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IMPLEMENTATION STUDIES FOR A RELIABILITY-BASED STATIC STRENGTH CRITERIA SYSTEM

Volume II, Implementation

M. C. Campion, W. D. Campbell, J. W. Chapman, et al.

Lockheed-Georgia Company

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The proposed reliability-based static strength criteria system described in AFFDL-TR-67-107, Volumes I-III, was reviewed to determine the data requirements and available, the implications of such an approach on the structural design process, methods by which implementation can be achieved without discontinuity, and necessary changes to specification and handbooks. Volume I describes the studies made using data for the C-141 cargo transport. Volume II describes the findings and includes five appendices. The principal conclusions are that insufficient data exists for the imminent implementation, but that studies of the relative reliability of different configurations and components or of different conditions at the same location would provide a short term means of using the system to gain familiarity and confidence.

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Volume II, Implementation

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Lockheed-Georgia Company

FOREWORD

This report was prepared by Lockheed-Georgia Company, Marietta, Georgia, for the Design Criteria Branch of the Structures Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, under Air Force Contract No. F33(615)-71-C-1129, Project No. 1367, "Structural Design Criteria," Task No. 136714, "Airframe Structural Design Adequacy."

The study which led to this report was conducted by the Advanced Structures Department of the Lockheed-Georgia Company during the period February to November 1971, with Mr. M. C. Campion as Program Manager and Principal Investigator. Major support was also given by personnel from the General Structures and General Aerodynamics Departments. In addition to the authors named, the contributions made by Mr. E. J. Bateh (materials data), Mr. W. J. Huggins (operational data) and Miss B. R. Thompson (programming) are freely acknowledged. Mr. George E. Muller of AFFDL (FBE) was the Program Monitor for the Air Force, and his encouragement and assistance are also acknowledged.

For reference purposes, the report carries the Contractor's internal reference SMN 311. The report was submitted by the authors in November 1971.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Gordon R. Negaard, Major, USAF
Chief, Design Criteria Branch
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Air Force Flight Dynamics Laboratory

ABSTRACT

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LIST OF SYMBOLS

AMSTR	Intended mean strength of the structural design
DF	Design factor = FS(1 + MS)
dx, dX	Interval width
DSNLD	Factored load used for sizing the structure
δP_f	Probability of failure when strength is in the interval $x \pm \frac{1}{2} dx$
F_{bru}, F_{bry}	Ultimate and yield strengths in bearing
F_{cy}	Yield strength in compression
FS	Design factor of safety
F_{su}	Ultimate strength in shear
F_{tu}, F_{ty}	Ultimate and yield strengths in tension
GWT	Design gross weight
MS	Design margin of safety
n_z, N_z	Normal load factor
p	Probability of a value in the interval $x \pm \frac{1}{2} dx$
p_{s_M}, $p(\bar{x}_i)$	Probability that mean strength is in the interval $x \pm \frac{1}{2} dx$
p_{x_s}, $p_s(x)$	Probability that strength is in the interval $x \pm \frac{1}{2} dx$
P	Probability of value less than (or greater than) X
P_F	Probability of failure
P_L	Probability that load equals or exceeds X
P/PU	Test strength as fraction of intended ultimate strength
R	Reliability = $1 - P_F$
s	Standard deviation

$\bar{S}$	Indicated mean strength of the fleet
S_{ALL}	Design allowable strength (number of standard deviations below the mean)
SUMA, SUMB	Fractions of total allotted to A and B families of double-family distribution
TF	Test factor (applied to UNFLD)
UNFLD	Unfactored design load used as basis for sizing the structure
v	Coefficient of variation = S/mean
v_A, v_B	Coefficients of variation of A and B families of double-family distribution
v_T	Resultant coefficient of variation of double-family distribution
W	Aircraft weight
WS	Wing station
x, X	General variable
$\bar{x}_A$, $\bar{x}_B$	Means of the A and B families of a double-family distribution
x_i	Particular value of the variable
$\bar{x}_i$	Particular value of the probable mean
$\bar{x}_T$	Resultant mean of double-family distribution
X_T	Test result
y, Y	Gumbel transform of the probability (P) of a value less than X

SECTION I

INTRODUCTION

Many attempts have been made to achieve the realization of techniques for applying reliability methods to the definition of structural strength. The most comprehensive of these was prepared by Innes Bouton and others and is described in AFFDL-TR-67-107. The three volumes of that report of that report discussed previous methods and derived proposed methods covering both time-independent (static) and time-dependent (fatigue) strength. The full range of interactions with non-structural, operational, executive, and contractual areas was discussed.

The study described in the present report was aimed at reviewing the proposed method for applying probabilistic techniques to the assessment of static strength reliability. This review was to identify the data requirements of the proposed method, the necessary changes to specifications and design handbooks, the interfaces with non-structural design areas and the steps to be taken during implementation of the method.

(Repeated from Volume I.)

SECTION II

SUMMARY

A clear understanding of the various operations incorporated into the proposed static strength reliability analysis of AFFDL-TR-67-107 is necessary to its successful implementation. Section III provides a simple worked example which illustrates each step in turn using, first, dummay data and then realistic data. The categories of required data are defined.

Sections IV through IX discuss each category in turn, by means of studies of data pertinent to the C-141A cargo transport aircraft. Section X then summarizes the findings in the form of a trial application of the method to the wing of the C-141A.

Sections XI and XII discuss, respectively, the updating of the data to reflect the state of knowledge at each stage during the design and operational life of a vehicle, and the form in which the required data might be standardized.

Specific steps required to achieve the short-term and long-term implementation of the method are described in Section XIII, and the necessary changes to existing MIL-A specifications and AFSC Design Handbooks are summarized in Section XIV. Section XV contains the conclusions and recommendations resulting from the study.

Five appendices follow the main text. Appendix I outlines a technique for the use of bi-modal (double-family) statistical distributions; the Gumbel distribution of extremes is employed as an example, but the method is valid for a range of statistical distributions. Appendix II contains the basic equations of the computer program used in the study; this uses double-family Gumbel distributions, a constant calculation interval, and employs Bayes' theorem to incorporate the effects of test results, but is otherwise similar to the original program; many of the intermediate results are, however, printed. Appendix III describes the program, its input requirements and operation.

Appendix IV contains sample runs made with the program, and Appendix V shows the analysis of load and strength data using double-family representations.

(Repeated from Volume I.)

SECTION XI

UPDATING OF DATA

11.1 Introduction

Reference 1 stresses the continuous nature of the process of establishing the structural reliability. The specific items to be updated are described in this Section, with the practical means of doing so described.

11.2 Data Items

The three fundamental data categories are:

- o load spectrum
- o error function
- o strength distribution

and each will change periodically during the total lifetime of a specific aircraft. The particular points at which data revisions are most likely, and which permit progressively updated reliability estimation, are:

- o Initial Design Stage
- o Detail Design Stage
- o After Detail Design, but before Static Testing
- o After Static Testing, but before Design Revision
  Final Design, but before Operation
- o During Operation

Each is discussed separately below.

11.3 Revision Stages

a. Initial Design

During initial design, the load spectra must be based on assumed utilization, assumed aerodynamic and inertia distributions over the airframe and assumed probabilities of occurrence of different conditions. An error function can arbitrarily be selected from one of the "standard set", or can be based on past test experience

within the particular company. Strength distribution data will be selected from the chosen material data, with, advisedly, allowances for the effects of fabrication and assembly which reflect any unconventional features. Predictions can be made of the reliability, assuming values for the various parameters.

b. Detail Design

By the time that the detail design stage is reached, some additional information will generally be available. Revised load spectra will have replaced the preliminary data; some component test data will usually have been accumulated, particularly for any novel design features, and will permit a revised error function to be selected. If new construction methods are proposed (fasteners, say), then sufficient test data will perhaps be available to indicate the variability of the process and so to permit revision of the strength distribution. A second set of reliability estimates is possible.

c. Before Static Testing

At the end of the detail design stage, but before static testing, a third set of reliability estimates can be calculated. This will reflect any additional data gathered up to this time, particularly in the strength distribution area. The reliability predictions will remain based on assumed test results.

d. After Static Testing

The static test results will have one of two effects. Either the design goal will have been met, th confirming the predictions, or it will not have been met. In the latter event, two courses of action are possible: redesign will be performed in the failed regions, representing a further iteration, or the design and operating conditions will be revised to correspond to achievement of a lower loading at the original reliability, or a lower reliability at the original load.

e. Final Design

After any redesign or re-analysis has been completed, but before the aircraft enters service, a further reliability assessment can be made. This will still be based on assumed utilization and assumed load distribution data, but will reflect all strength data accumulated up to this time.

f. During Operation

Operational data will be appropriate to two distinct types of revision of the reliability estimate. The first is the obvious one of permitting realistic load spectra to be formulated, and the second is a very important one which is usually overlooked. Each flight experience of a particular load is an additional test to that load level. Now, it has been shown that the influence of testing to low load levels is insignificant, but each and every aircraft that experiences a high load level provides a further data point which adds to the knowledge required to predict a better reliability.

Periodic updating can be performed as data is accumulated; this should not be too frequent, for economic reasons, and determination of the appropriate times will depend on individual circumstances.

11.4 Operational Data Recording

a. One of the greatest potential areas for acquiring new and better structural design data lies within the Air Force's Aircraft Structural Integrity Program, ASIP. As a part of the ASIP, each aircraft system must have an Individual Aircraft Service Life Monitoring Program, IASLMP; and as a part of the IASLMP for the more critical systems, a number of aircraft in each fleet is to be equipped with Multi-Channel Recorders (M-CR).

The need for multi-channel recorders has been a recognized part of Air Force planning for at least ten years. Some recorders have even been developed and used with varying degrees of success, but with limited applicability. Starting in 1968, the Air Force laid plans for a new and more universal recording system. The AFLC, through its several AMA's, gathered data on the type of information needed to effectively carry out the IASLMP's on a wide variety of aircraft. These data were synthesized by ASD, along with other known and projected requirements, to prepare a set of recorder specifications. In June 1970 ASD, under the auspices of AFLC, let a contract to develop a new 24 channel digital recording system and a ground playback unit. That system is still under development at this writing. A unique feature of the new system is that a single basic recorder unit will be suitable for all types of aircraft. To accommodate peculiar requirements of different types of aircraft, the system includes development of four different converter/multiplexer units, each of which is compatible with the one recorder module. Current plans call for the initial production of about 140 recorder systems, with a contingency buy of approximately 140 additional systems. A portion of most "first-line" aircraft fleets (ranging from about 5 to 20%) are tentatively scheduled to receive the recorders, with first installation starting in late 1972.

b. One of the major objectives of the multi-channel recorder program is to provide a better tool by which to accomplish structural fatigue tracking. In fact the entire program to date has been oriented toward - and largely justified by - the structural fatigue problems. However, because of the high commonality between the data needed for fatigue design or tracking and the data required to develop new statistically

TABLE XIX

PROPOSED LIST OF MULTI-CHANNEL RECORDER PARAMETERS FOR THE C-141.

NO.	ITEM	NAME
1.	T	Clock Time
2.	H_p	Pressure Altitude
3.	V_e	Equivalent Airspeed
4.	N_Z	Normal Acceleration at C.G., g's
5.	N_Y	Lateral Acceleration at C.G., g's
6.	$\dot{\theta}$	Pitch Rate
7.	$\dot{\psi}$	Yaw Rate
8.	δ_e	Elevator Position
9.	δ_r	Rudder Position
10.	δ_f	Flap Position
11.	V_g	Ground Speed
12.	β_N	Nose Gear Steering Angle
13.	σ_1	Strain at Location 1
14.	σ_2	Strain at Location 2
15.	σ_3	Strain at Location 3
16.	σ_4	Strain at Location 4
17.	σ_5	Strain at Location 5
18.	ΔP	Cabin Pressure Differential
19.	W_f	Total Weight of Fuel
20.	S.S.	Squat Switch Make-or-Break Signal
21.	DD1	Date
22.	DD2	Serial Number
23.	DD3	Base of Assignment
24.	DD4	Initial Cargo Weight or Cargo Update
25.	DD5	Total Initial Fuel Weight

based strength design criteria, this latter area will inevitably benefit. A second stated objective of the Multi-channel recorder program is to accumulate data for use in the structural design of future aircraft systems. The opportunity offered by this objective is obvious. After the recorder installations are made and records accumulated for a time, certain of the data on each aircraft system will "mature" to the point that further recording produces no new intelligence. When this happens the recorder program can and should be redirected toward goals that are allied more specifically to the statistical strength criteria. A hypothetical example of such a switch is given in the second following paragraph.

c. Since the C-141 has been used for illustration in other sections of this report, the same theme is followed here. Table XIX shows the list of parameters that have been selected by WRAMA for the M-CR program on the C-141. Each of these parameters - either singly or in combination with others - is believed to produce something of value either directly in a contemporary fatigue tracking process, or in the derivation of new fatigue criteria, or both. Several of these parameters should be useful also in deriving new statistical strength design criteria. For example, normal acceleration at the center of gravity, N_Z, is a valuable parameter in its own right since it is a direct measure of the gross symmetric response. When N_Z experience is properly sorted by weight, speed and altitude, subsequent peak counting of the data provides the type of statistical distributions required in the determination of strength levels. A further refinement is attainable by a joint analysis of N_Z with elevator deflection. Besides allowing a separation of symmetric gust and maneuver responses, such an analysis should also afford the collection of good statistical samples of abrupt pitch maneuvers - an important design area about which little is known for cargo aircraft.

In a similar manner N_Y can be sorted and peak counted for use in lateral load predictions, and it can be jointly analyzed with rudder deflection to fill the gap in knowledge about abrupt rudder kick maneuvers.

d. One other illustrative example is worthy of noting here concerning possible future direction of the M-CR program. If the C-141 program is successfully implemented and prosecuted, certain of the parameters will attain a statistical stability after which they need not be recorded full time. The resulting surplus of recorder capacity may be used effectively to fill knowledge gaps such as that concerning the phasing of PSD loads. In gust analysis current PSD methods allow, for example, a fairly precise, but separate, determination of shear, bending and torsion at a given structural location; but the phasing of these three vectors in a deterministic strength analysis is largely a guessing game. The addition of strain gage clusters or rosettes at selected stations could provide real li'' samples of the amplitude and frequency relationships among two or more load vectors. Data such as these will be essential in future designs in order to express applied loads and structural strength in a common set of terms.

e. In summary, the multi-channel recorder program(s) is viewed as having great potential in gathering data for use in applying the new structural reliability concepts. In particular, statistical information on loads and the loads environment will be developed in both the volume and detail necessary for a rigorous statistical load analysis.

SECTION XII
STANDARDIZED DATA

12.1 Data Categories

a. The proposed probabilistic system of criteria is intended to provide desired structural reliability levels for normal operation and for a reasonable degree of overload. The basic concept is that the statistical variations of load and strength are jointly incorporated into the risk assessment. A convenient approach would be provided by charts relating the required design and test factors to the reliability levels in terms of parameters describing the load strength distributions, the error function and the number and type of tests.

b. The study described in this report reveals that the "demonstrated" reliability is indeed a function of all of these parameters. Furthermore, simultaneous consideration of both normal (limit) and overload (omega) conditions will seldom be possible because the permissible load level (streng will generally be different. Each structural location will require separate analysis, due to the fact that both the load and stre. gth distribution will differ from point to point.

12.2 Load Data

a. Theoretically, it would appear possible to develop a single load spectrum for each location, which would contain the total load occurrence properties for an aircraft lifetime. The statistics required to achieve this goal are not available, even on aircraft which have accumulated extensive operational experience. For example, information is required on the probabilities of

1) weight and weight distribution
2) speed and height
3) type of load condition (gust, pull-up, rudder kick, etc.)
4) level of loading (in terms of a basic parameter)
5) time history of loading (to describe the local loading)
6) associated load systems (pressure, thermal gradient, etc.)

and these probabilities are clearly not independent, so that the resultant probability of each combination is needed.

b. Some degree of standardization may be feasible, even if it is more arbitrary than statistical in origin. For example, gust velocity descriptions are already employed in fatigue analysis and would be directly usable. Normal load factor spectra exist in a suitable form in existing criteria (reference 2) and these distributions can be regarded as standard for the appropriate category of aircraft and the appropriate type of mission.

c. Many of the remaining areas require extensive data collection and analysis. This is particularly true of the asymmetric flight conditions which are of increasing significance as sweepback increases and aspect ratio reduces.

d. For the initial use of the proposed system, one possible means of filling the void would be for an assumed set of data to be derived from what data can be assembled. Such synthetic "statistics" must be regarded as artificial, but would at least permit comparison of different aircraft, different locations on the same aircraft or different structural designs of the same location.

e. The necessity for an adequate probabilistic prediction of the utilization of the aircraft becomes as great as in fatigue analysis. However, in addition to the average or typical conditions for each segment of the mission profile, it will be necessary to derive (or assume) the shape and dispersion about this mean. Without this detailed level of data, no realistic estimate of the risk of failure can be made; the alternative is to ignore the probability distribution of the loads, to assume a known certain load and to base the reliability estimate solely on the variation in strength. While this may be conservative, it negates most of the advantages implicit in the proposed method of reference 1.

12.3 Strength Data

a. Extensive material strength data already exists as the necessary means of establishing the published design allowables. Although the allowables themselves represent only one discrete point in the distribution, the required data should be accessible; the form of data required consists of the mean and standard deviation and the shape of the distribution to be used. For reliability analyses, it should be remembered that the lower tail of the distribution is most important in the assessment of the risk of first failure (mean time before failure estimates are not appropriate), and distributions must be chosen with this in mind. Double-family distributions may be appropriate (see Appendix I), and if these are employed, the necessary material strength data will generally contain five parameters.

b. Most of the data described above relates to the basic properties of the material as delivered to the aircraft manufacturer. The structural strength of the final product will reflect variations imposed by all of the operations inherent in fabrication and assembly (the time-dependent effect of service wear and tear is not considered in the context of the present study, but may need to be examined).

Data on the strength of various detail configurations, such as lugs, fittings, joints, etc. exists in a random manner, but usually in insufficient quantity to provide adequate statistical distribution data. The acquisition of such information is of paramount importance to the success of the proposed method.

c. Appendix V gives examples of the analysis of typical samples of data of material strength and joints. These reveal that the conventional assumption of normal distributions may not be desirable, and that better correlation with observations can be achieved with skewed distributions (either single-family or double-family).

d. Two approaches are possible for the derivation of the required information on the strength of fabricated structures. The first involves the separate assessment of the basic material properties and of the effects of fabrication, the two being subsequently combined to give the resulting distribution (the computer program of Appendix II provides this facility). The second approach involves only the statistical

analysis of large numbers of identical components to assess the resultant strength variation directly, without attempting to ascertain the contributions due to the separate causes.

Since so much material data exists, the first approach recommends itself, but a deliberate effort is required to determine the effects of the various fabrication and assembly operations in statistical terms.

12.4 Error Functions

a. The importance of this function has been illustrated in Sections III and VII. The formal recognition of the probable discrepancy between the intended strength and the actual achieved strength is perhaps more important than the particular function used, since the use of Bayes' theorem tends to be self-compensating once the necessary testing is performed. The function describes the discrepancy (however caused, whether by design errors, design tolerances, deliberate under-design, quality control errors or fabrication and assembly errors) in terms of the distribution of the probable mean strength of the design.

b. Section VII describes four types of function suitable for the definition of the probable discrepancy. While the use of some standard function is possible, it does not permit the recognition of the experience of a particular constructor with his own policies and practices. Comments on the four types of function are:

   1) The Jablecki function, as used in reference 1, uses static test data from the 1940 period (reference 3); it is implicitly assumed that the ratio of test strength to design strength describes the ratio of mean strength to intended mean strength, but it is equally apparent that no account is taken of the probability that the test article was weaker or stronger than average.

   2) Freudenthal, in reference 4, attempted to update the Jablecki data. The relevance of the data used is not altogether clear; the comment is made that the results are representative of current practice, yet data are included for aircraft of the pre-1950 period.

3) Both of the above functions are most easily used by basing the constants on a curve-fit at two selected points. The same concept can be employed using the Gumbel distribution of minima instead of the Bouton-Jablecki equation (linear log-log relationship) or the Freudenthal exponential function. Any other suitable distribution can also be employed.

4) The fourth type of distribution is the double-family distribution described in Section VII. This technique may be the most suitable for fitting past experience, or for permitting recognition of the additional risk of design error when a radically new type of construction is being employed before the required analytical tools have been fully developed.

c. As will e shown later, using the single-family Gumbel distribution of varying dispersion, the degree of dispersion (coefficient of variation) has relatively little influence once the test results have been incorporated. A relatively low risk would probably be introduced by the adoption of a standard error function.

12.5 Presentation of Standard Data

a. Loads Data:

1) Standard load spectra expressed in terms of some design value (such as $N_{Z_{Max}}$) and of a given shape can be presented in tabular form as in reference 5.

2) Mission profile and utilization data may be standardized for particular aircraft or mission types, but will probably be best defined for each system as part of the specification.

3) Data determining the combinations of mechanical and thermal conditions, the combinations of pilot and auto-control action, and the combinations of external (gust, say) and internal (subsystem) effects cannot be standardized and must be derived in probabilistic terms for each specific design. In many cases,

this will not be possible during the design phase; some standard arbitrary distribution of effects may be appropriate in this phase for describing the probabilities of engine failure, auto-stabilizer runaway, cabin pressure malfunction, etc.

b. Strength Data:

1) For each type of basic material, the present system of discrete design allowables must be retained for association with the design loads to permit the physical sizing of the structure. The values need not be the present "A" or "B" values per se, but the retention of these is obviously advisable.

2) For the reliability calculations, the mean and standard deviation (or coefficient of variation) is required. These data are not generally as readily available.

3) In addition to material data, the statistical effects of fabrication and assembly are required. Typical values for the various processes (rolling, stretch-forming, machining, etc.), for various jointing methods (riveting, bolting, welding, bonding) and for the actual assembly process (fitting stresses) will be required, and can be presented in tabular form.

c. Design and Test Factors:

1) For any given set of the other parameters, it is possible to derive relationships between the design factor, the test factor and the reliability indicated by the test result. Two basic assumptions will simplify the presentation in different ways. The first requires the adoption of a constant design factor (say 1.5), but varies the test factor to the value required to "demonstrate" the required reliability. Typical relationships are shown in Section IX.

2) The second alternative, which may be simpler in form although less versatile, is to assume the design and test factors to be equal. This retains the concept in the current system, but must not be interpreted as having the same meaning.

3) Since the "demonstrated" reliability is a function of the load spectrum, the error function, the strength distribution and the number of tests, it is obvious that a complex set of charts must result. For the particular choice of

- o design factor = test factor
- o one survival test
- o single-family Gumbel distribution of maximum load per aircraft lifetime (mean at 100)
- o single-family Gumbel distribution of minimum strength (mean at 100)
- o single-family Gumbel distribution of error (mean at 100), where error is the ratio of achieved mean strength to intended mean strength

the curves shown in figures 75, 76, and 77 show the manner in which the factor can be chosen to realize a defined reliability.

4) Figure 75 shows the reliabilities (R) corresponding to variations in the load dispersion (L_V = coefficient of variation of the distribution of maximum load) and in the design and test factor. Separate carpet plots are shown for three levels of error dispersion (E_V), but show little variation with E_V. All three carpets are for strength coefficient of variation (S_V) of 0.04, and for one survival test. A series of plots of this type can be derived for each strength distribution (for each material type and construction type).

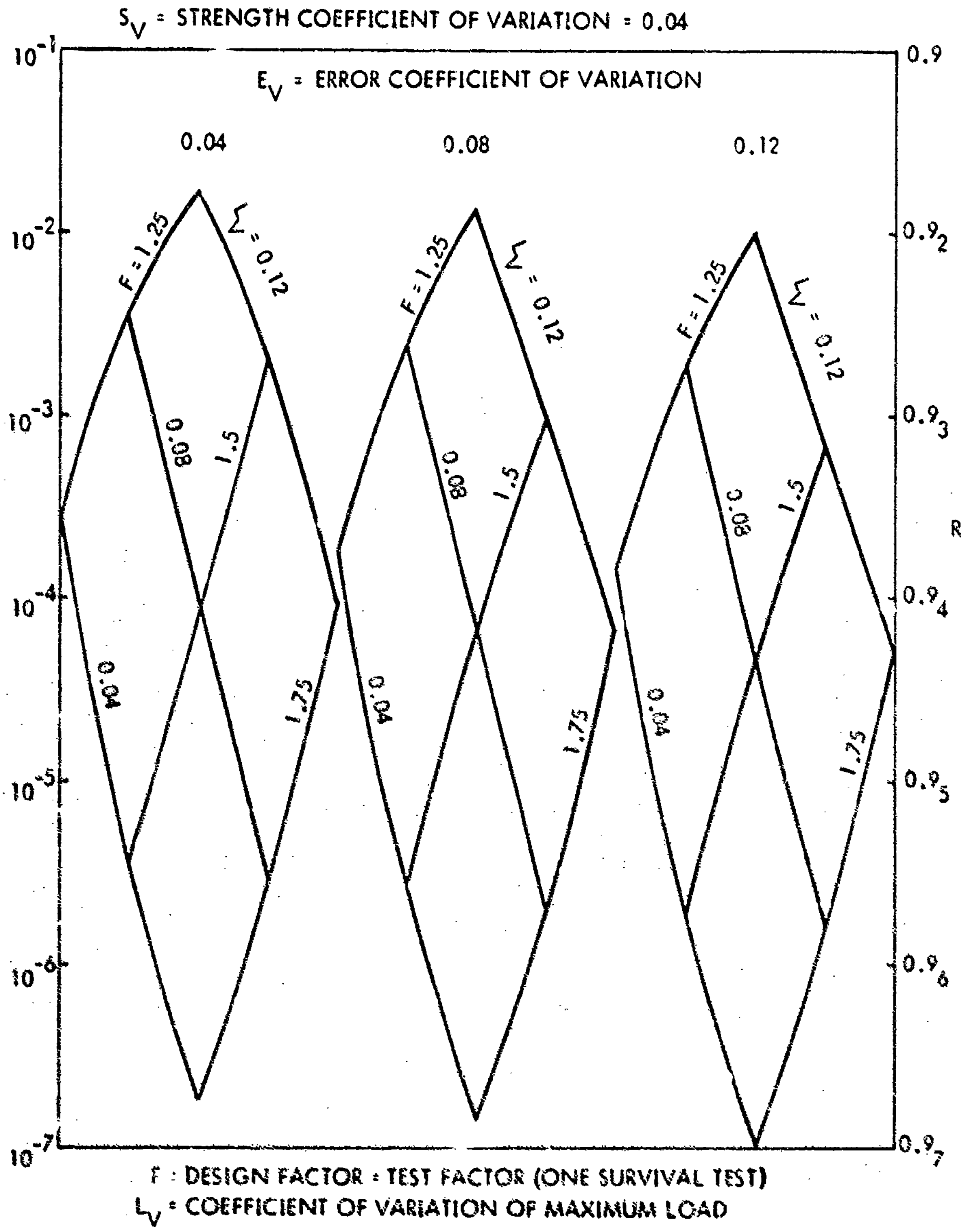

FIGURE 75 DESIGN/TEST FACTOR TO GIVE CHOSEN RELIABILITY, FOR CONSTANT STRENGTH DISPERSION, VARYING LOAD AND ERROR DISPERSIONS

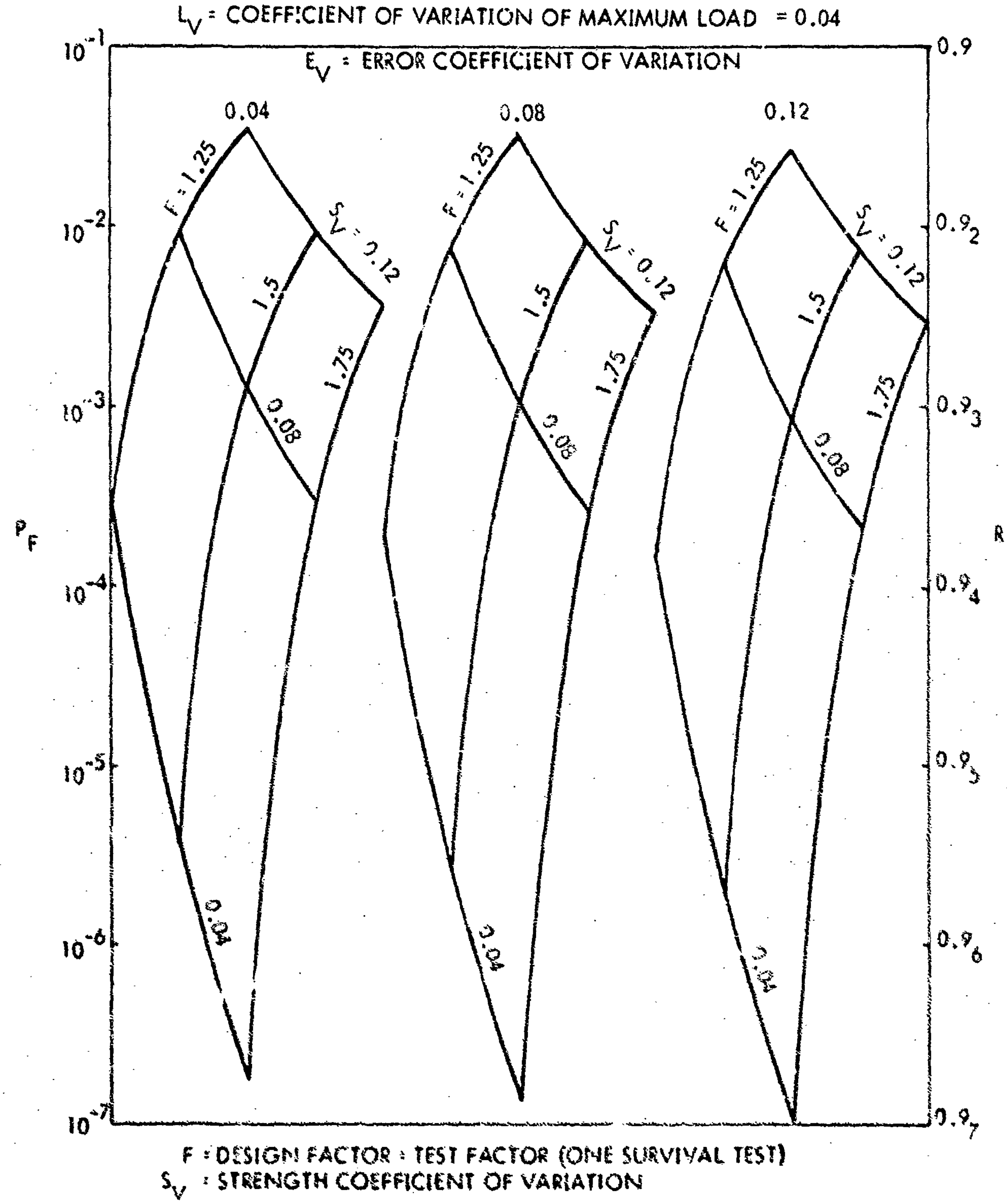

FIGURE 76. DESIGN/TEST FACTOR TO GIVE CHOSEN RELIABILITY, FOR CONSTANT LOAD DISPERSION, VARYING STRENGTH AND ERROR DISPERSIONS

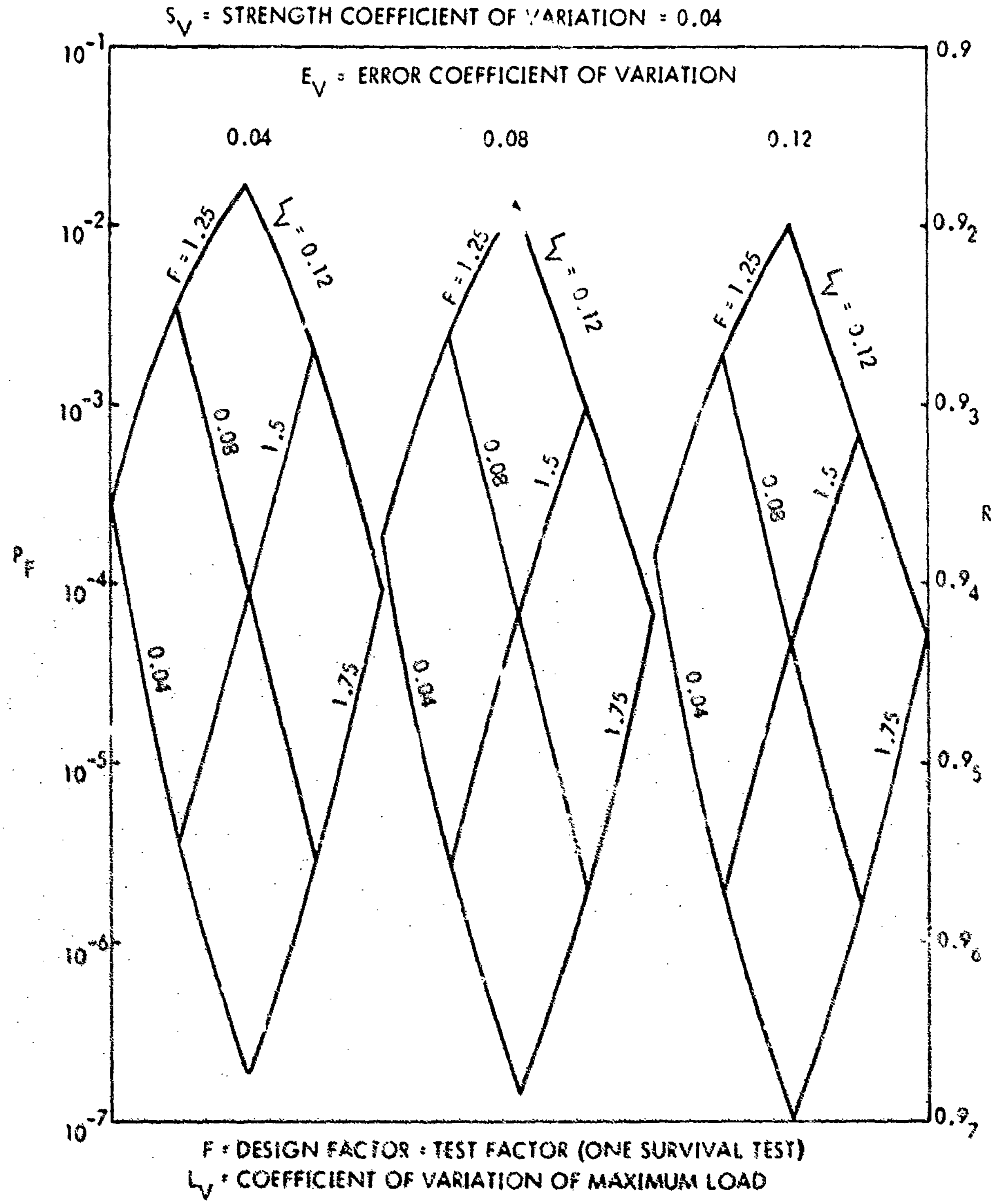

FIGURE 75 DESIGN/TEST FACTOR TO GIVE CHOSEN RELIABILITY, FOR CONSTANT STRENGTH DISPERSION, VARYING LOAD AND ERROR DISPERSIONS

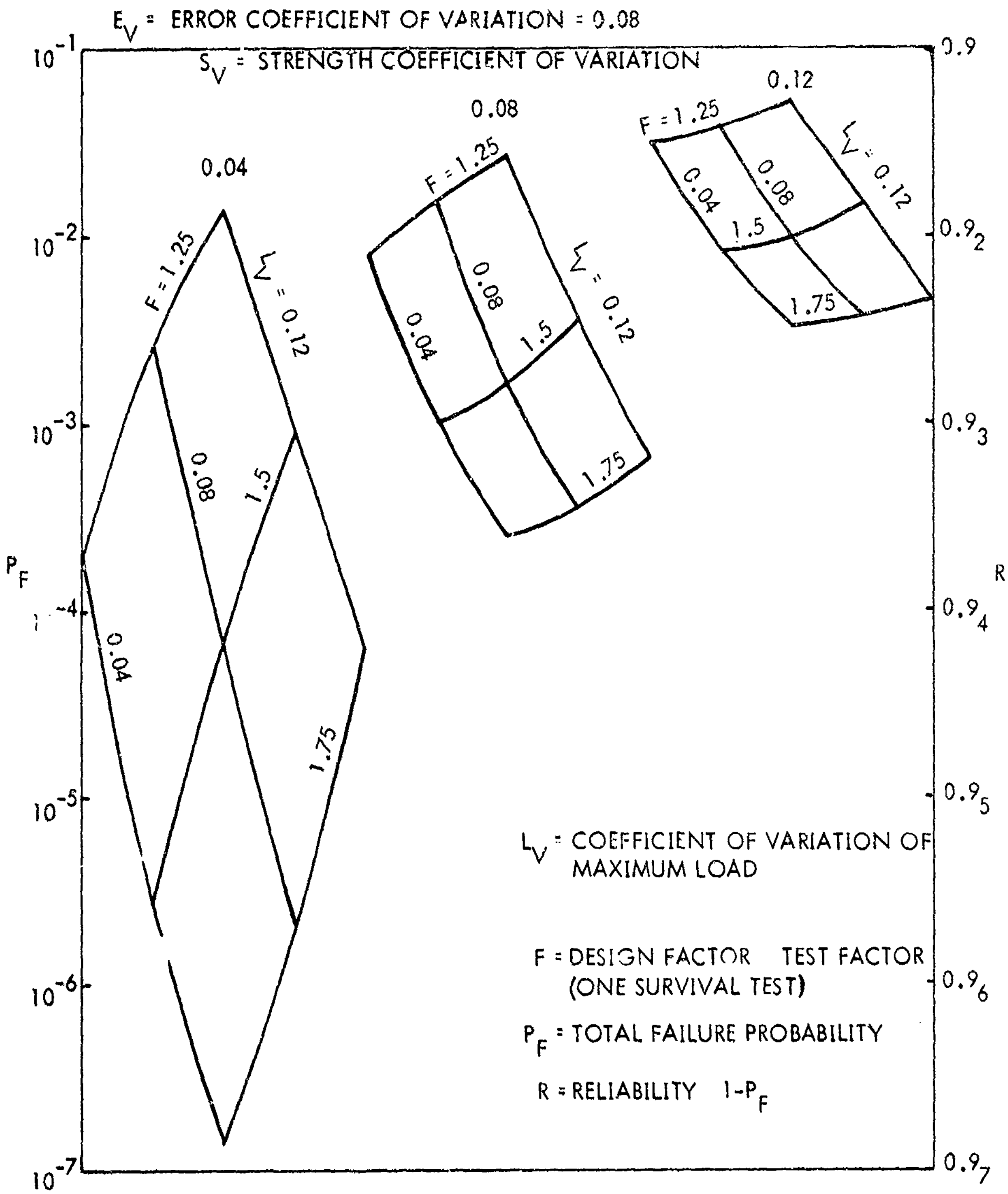

FIGURE 77 DESIGN/TEST FACTOR TO GIVE CHOSEN RELIABILITY, FOR CONSTANT ERROR DISPERSION, VARYING LOAD AND STRENGTH DISPERSIONS

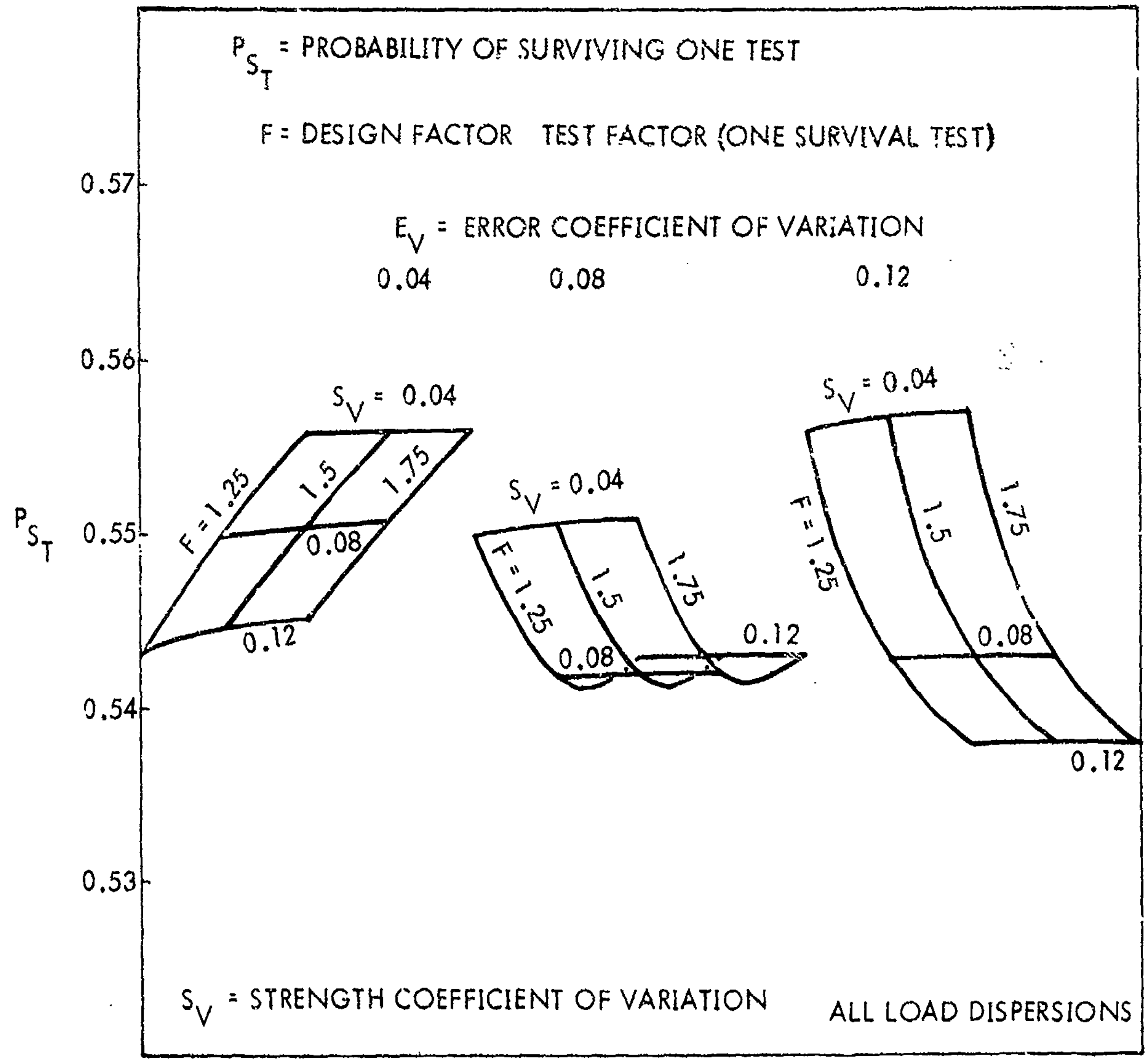

FIGURE 78   PROBABILITY OF SURVIVING ONE TEST

5) Figure 76 is a similar series of plots, but the vari ion in each carpet is with the strength coefficient of variation (S_V). The complete set is for a given coefficient of variation of maximum load. ($L_V = 0.04$). The influence of the error coefficient of variation is again slight. A set of this type can be derived for each of the standard load spectra, and used where necessary to guide the choice of material or construction method suitable for the attainment of the required reliability.

6) Figure 77 is for a constant error variation ($E_V = 0.08$). Each carpet shows the combinations of load coefficient of variation (L_V) and design/test factor and is for a separate strength coefficient of variation (S_V). This form of presentation is probably the most useful in the earlier design stages, when the design iteration process is being applied to determine the layout and member sizes. The example (figure 77) illustrates the importance of the strength variation, implying for example, that a reliability of 0.9999 cannot be achieved with strength variations exceeding about 0.06, unless very high design/test factors are used.

7) Figure 78 illustrates the associated probabilities of surviving the survival test. This quantity is independent of the load spectrum, and for the chosen equality of design and test factor, shows surprisingly little variation with the strength or error le els.

SECTION XIII
STEPS TOWARDS IMPLEMENTATION OF THE PROPOSED SYSTEM

13.1 Introduction

a. The proposed system of probabilistic criteria, aimed at providing the desired degree of static strength reliability, offers several advantages over the present deterministic system. Nevertheless, it is necessary for the essential features of the system to be introduced in a manner which assures continuity with the present system. A two-stage process is suggested in this Section. Initially, there will be insufficient data available to implement the total aim of establishing a single reliability figure covering the entire life of the fleet; however, even restricting the calculations to those flight conditions for which data is available will serve several useful purposes.

b. There is an inherent resistance to new methods, especially when the existing techniques appear to be adequate. Familiarity (with the old) breeds contempt (for the new). This is particularly true in this context, since the proposed method requires a radically different interpretation of testing. Furthermore, a number of decisions will be required which must be based on the correct understanding of the probabilistic processes; since this is an unfamiliar subject to many of those who will be responsible for the decisions, it is vital that the physical, rather than the mathematical interpretation of each step in the chain should be kept clear.

c. The use of the method as a means of comparing the relative risk rates of various designs, of various flight conditions and of various structural locations offers an opportunity to achieve familiarity with, and confidence in the method. It will also encourage the acquisition of the data required for the eventual implementation of the complete system.

13.2 Initial Implementation

a. The establishment of absolute reliability values requires assurance that every possible cause of failure is considered. As this cannot be guaranteed, it is proposed that the method be used to establish the separate probabilities of failure for:

- o different structural designs under the same loading conditions, in order to indicate the optimum means of securing the highest reliability
- o the same structural location for different loading conditions (maneuvers, gusts, landing, etc.), in order to assess the relative risks associated with different flight cases; it is an inefficient design which has a high survival rate under gust loads, but a high risk of failure during landing
- o various structural locations under the same loading conditions; this will provide a means of early assessment of areas of the structure which will be a potential source of trouble.

b. In this context, it will be possible to study the influence of subsystem failures in meaningful terms, so that the overall optimum can be established for the relative penalties associated with the addition of redundant circuits, or with the addition of structural weight to withstand the loads resulting from a less reliable subsystem. Information from such studies will be applicable to the necessary decisions which involve both structural and non-structural areas.

c. Interfaces between structural design and structural test decisions will be studied, since the method provides information enabling conscious trade-offs between test load levels and the probability of destroying the test specimen. The necessity for testing to a particular load level can be studied in terms of the reliability level "demonstrated". The necessity for redesign can be interpreted realistically in the same terms.

d. Studies of this type should be performed on a number of existing operational aircraft, as well as on a number of new designs. This will provide an insight into the relative importance of various parameters, as well as indicating the implied reliabilities of existing aircraft for the conditions studied.

e. It is suggested that these initial studies should be based on the same limit design factor as was used in the deterministic criteria system. The interpretation of actual test results will be in terms of the reliability indicated by the test results. This will provide the desirable continuity with existing methods.

f. During these initial stages, it is imperative that every inducement be given to the collection and analysis of data required by the full method. This must include:

- o load spectra for different conditions
- o probabilities of different speed-height-weight conditions
- o strength distribution data for basic materials
- o strength distribution data for fabricated components using a variety of fabrication and assembly methods
- o achieved strength versus intended strength data to verify the actual discrepancy levels

13.3 Final Implementation

a. It will not be possible to achieve a completely probabilistic system with any real meaning until a great deal more statistical data have been derived. However desirable a single reliability value might appear, the judgment as to what is acceptable will remain arbitrary. Who can decide logically whether 0.99996 is acceptable but 0.99994 is not?

b. Because of this dilemma, it is probable that the relative risk assessment technique will prove to be worth retaining even when all of the necessary data is available. This provides not only a means of indicating potential sources of weakness; but also a tool by which the intended utilization can be modified in such a way as to make the best use of a given airframe.

13.4 Flight Testing

One further area which would repay study during the gradual implementation of the system is the relatively high risk associated with deliberate flight testing to improbable corners of the flight envelope. The probabilistic load spectrum for such aircraft remains at a level of 1.0 up to the maximum intended load, which changes the failure probability from that predicted for the operational aircraft. Studies of this feature would probably enable a more cost-effective structural flight test program to be devised which is still capable of demonstrating all necessary conditions at a lower risk of loss.

13.5 Overload Capacity

a. Some part of the present factor of safety has long been recognized as providing a margin of strength to cater for occasional exceedences of the placarded limitations. The real overload capacity of an airframe is, however, far from consistent, especially as the structural optimization is based on the factored limit load system. A frequent problem is the solution of the question: if a factor of safety of 1.5 exists at load level P, at what load level does the factor of safety become 1.0 (or 1.2, or 1.3)?

b. Figure 79 illustrates the random nature of the overload capacity of the total structure. Suppose the external load, P, at some structural location to vary linearly with the basic parameter (say N_Z), and to pass through the origin, as shown by curve A. The unfactored limit values are N_L and P_L; with a factor of safety of 1.5, the design load is $P_U = 1.5\ P_L$, so that the permissible N_Z with a factor of safety of 1.0 is simply $N_U = 1.5\ N_L$.

Now consider the existence of a superimposed loading independent of N_Z (this might be a C_{M_O} load system or an internal pressure, for example). Curve B results if this loading adds to the original loading. For the same limit load factor, N_L, the unfactored load is now P_{L_B} and the factored load is P_{U_B} (factor of 1.5). For a factor of safety of 1.0 the permissible N_Z is now N_{U_B} which is clearly greater than the first value, N_U.

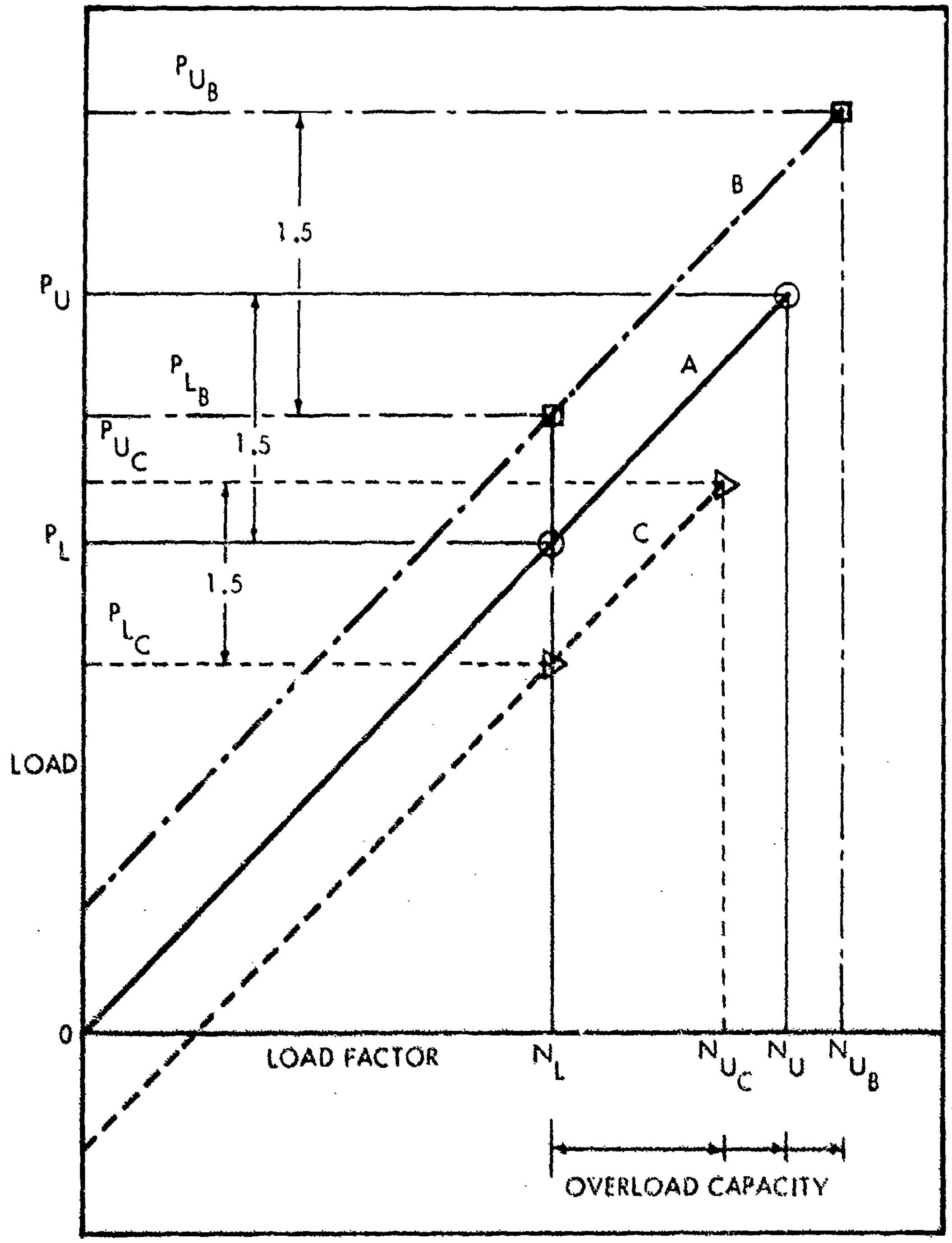

FIGURE 79 DESIGN LIMIT AND FACTORED LOAD AND OVERLOAD CAPACITY

If the superimposed load system relieves the varying load, as in curve C, the loads P_{L_C} and P_{U_C} result, the implied overload capacity being N_{U_C}, which is less than N_U.

Hence, the overload capacity, N_U, of a given part is dependent on both the rate of change of load with loading parameter (N_Z), and on the value at zero load parameter. If the intercept represents a relief, the overload capacity will be less than the nominal value, but if it adds to the varying load, a greater overload capacity will exist.

c. Figure 79 represents the simplest of all conditions, a linear system. The quantity which reflects the overload capacity will be a local internal load; in general, this will not be a linear function of the external load, and the external load will not be a linear function of any parameter which can be used to define the operational limitations. It can be stated that the actual overload capacity of a given airframe varies from one location to another in what is virtually a random manner.

d. The relationship between the limit and omega (overload) design conditions to be used is vague. It must depend on the utilization of the particular aircraft, and on what is regarded as a judicious risk of failure. Studies of existing aircraft should be made to assess the actual patterns of exceedence of limit condition and the actual failure rates. From such studies, it will be possible to develop trends which will enable initial criteria to be established which represent continuity with present circumstances.

SECTION XIV

SPECIFICATIONS AND HANDBOOKS

14.1 General

a. The purpose of this section is to identify changes required to MIL-A-8860 through 8871, MIL-F-8785 and appr iate AFSC-DH series handbooks to implement the new desi... method.

Implementation of the new design method as a replacement for presently acceptable procedures is not possible at this time with the scant amount of appropriate statistical information which appears to be available.

b. Several of the previous sections of this report have reported the availability of statistical information and illustrated how it might be used to develop structural design conditions. In addition, it is very possible that much more statistical data is available for use in the new method than has been uncovered in this brief study. Surely, many aircraft manufacturers have in their archives data which is not generally available concerning aircraft they have designed and built and the Air Force files undoubtedly include much data which was not available or not necessary for use in this study. For example, Reference 1 implies that F-100 statistics concerning vertical tail loads in operational usage are available. However, in this study no vertical tail load statistics were uncovered.

14.2 MIL-A-8860 Series Review

a. To start the implementation of the new design method, it is proposed that appropriate statements be placed in the MIL-A-8860 series (reference 2) and in the AFSC-DH series (reference 6) to allow the use of statistical methods as an option. Then any requirement for which adequate appropriate statistical data are available can be met through the use of those statistics. Data and methods to be used would, of course, be subject to the approval of the procuring activity.

b. In Tables XX through XXIX the latest available revisions to the MIL-A-8860 series are reviewed as to applicability of the new design method at present and in the future, and data availability to meet each requirement where the new method is applicable. Comments are included concerning changes required to the subject paragraphs to implement the new system.

14.3 Proposed Changes to MIL-A-8860 Series

a. In this section, actual wording changes to the MIL-A-8860 Series are suggested which allow the use of the new design method as an option. The approach used results in a near minimum number of changes and requires the use of AFFDL-TR-67-107 and AFFDL-TR-71-178 as guides to implementing the system.

b. MIL-A-008860A (USAF) 31 March 1971

2.2 Add:

"AFFDL-TR-67-107 Quantitative Structural Design Criteria By Statistical Methods

AFFDL-TR-71-178, Implementation Studies for a Reliability - Based Static Strength Criteria System"

3. Add:

"Establishment of Criteria. It is intended that structural criteria be established on a rational basis. Criteria delineated in this specification and the other specifications in the MIL-A-8860 series shall be used unless other criteria are determined to be more rational or unless the criteria are found to be inapplicable because of the peculiarities of the aircraft under consideration. New criteria or methods which are proposed by the Contractor shall be rational and shall be submitted to the USAF for approval prior to use in structural design computations. Where sufficient statistical information are available, consideration shall be given to use of the methods of AFFDL-TR-67-107 and AFFDL-TR-71-178 to establish factored limit and overload (Omega) design conditions commensurate with prescribed structural reliability goals."

TABLE XX

MIL-A-008860A (USAF), 31 March 1971

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
[illegible]	Applicable Documents				Add AFFDL-TR-67-107 and AFFDL-TR-71-178
3	Requirements				Add statements permitting use of the above documents subject to approval of procuring activity.
3.3	Limit Loads	Yes	Yes	Establish limit factor of safety by methods of TR-67-107 and TR-71-178	Change to define limit factor of safety for statistical approach
3.4	Ultimate Loads	Yes	Yes	Establish overload (omega) factor of safety by methods of TR-67-107 and TR-71-178	Change to define overload (omega) conditions as being separately determined when statistical approach is used.
3.5	Deformations	No	No		General method, still valid
3.6	Load Redistribution	No	No		Add the overload (omega) deformation to be used with overload (omega) loads when limit and omega loads are determined separately.
3.7	Superimposed Loads	No	No		General Requirement, still Valid
3.8	Transient Response	No	No		General Requirement, still valid
3.9	Thermal Consideration	No	No		Thermal effects must be considered, but will be a function of other parameters selected.
3.11	Design Strength	Maybe	Yes	Strength statistics of materials available from test data, operational experience, etc. Fabricated structure data less comprehensive.	Change to recognize statistical variation of strength and its application to statistical approach.

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TABLE XX (Concluded)

MIL-A-008860A (USAF), Concluded

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
[illegible]	Damage Tolerance	No	Yes	Statistics for deriving limit and range loads can be used to establish damage tolerance levels.	3.12e needs change to be compatible with new system concerning factors of safety.
[illegible]	Design Weights	Yes	Yes	Establish design weights from mission profiles or usage data.	Change to allow statistical definition of weights.
[illegible]	Speeds	Maybe	Yes	Establish speeds from mission profiles or comparison with similar aircraft.	Change to allow statistical definition of speeds.
[illegible]	Reliability Scale				Add definition for use with new method

TABLE XXI

MIL-A-008861A (USAF), 31 March 1971

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
[illegible]	[illegible]	Maybe	[illegible]	[illegible] data [illegible] overall parameters	Add statement allowing statistical determination of any or all parameters.
[illegible]	[illegible]	[illegible]	[illegible] [illegible] design weights from mission profiles or usage data. [illegible] with statistical [illegible] on the data.	Add statement allowing statistical determination of weight-load factor combinations.
[illegible]	[illegible]	[illegible]	[illegible]	Apparently no statistics available. [illegible] developed.	
[illegible]	[illegible]	[illegible]	[illegible]	Probably not statistically determinate at present. Development possible except for speed-limiting [illegible]	
[illegible]	[illegible]	[illegible]	Maybe	[illegible] statistics available. Difficult to develop statistically.	
[illegible]	[illegible]	Maybe	[illegible]	Speeds may be established from mission profiles, comparison with similar aircraft and available data.	
[illegible]	[illegible]	[illegible]	Maybe	[illegible] statistical data. [illegible] profiles	
[illegible]	[illegible]	[illegible]	Maybe	Difficult to assess probabilities of power settings.	
[illegible]	[illegible]	[illegible]	[illegible]	No statistics found	
[illegible]	[illegible]				Not Applicable
[illegible]	[illegible]	[illegible]		[illegible]	

TABLE XXI (Continued)

MIL-A-008861A (USAF), Continued

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
3.13	Cockpit Enclosures, Bomb Bay Doors, Etc.	No	Maybe	None	
3.14	Stability Augmentation Devices	No	Yes	Failure data available, but much analysis required.	Add statement providing for statistical analysis of failure probabilities
3.15	Torque on Primary Control Survaces	No	No		
3.16	Tab Loads	No	No		
3.17	Unsymmetrical Horizontal Tail Loads	No	No		
3.18	Deformation of Doors Cowlings, Locks and Fasteners	No	No		Change "design ultimate loads" to "design factored (limit or omega) loads"
3.19.1	Steady Pitching Maneuvers	Yes	Yes	Use maneuver load factor statistics with mission profile or usage data parameters	
3.19.2	Abrupt Pitching Maneuvers	No	No	Apparently no statistics available concerning control motions	These arbitrary control motion could be applied to conditions developed from 3.19.1 parameters
3.19.3	Flaps-Down Pullouts	No	Yes	Apparently no statistics available for flaps-down load factors. Could be developed.	
3.19.4	Aerial Delivery Pull-outs	No	Yes	Load factor and speed statistics needed.	
3.19.5	Emergency Stores Release	No	No		

TABLE XXI (Concluded)

MIL-A-008861A (USAF), Concluded

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
3.19.6	Variable Sweep Surfaces	No	Yes	Could use load factor statistics together with mission profile data.	
3.20.1	Rolling Maneuvers	No	Maybe	Little available. Could possibly be developed.	
3.20.2	Sideslip and Yawing Maneuvers	No	Maybe	Statistics needed concerning use of rudder and occurrences and severity of engine failures.	
3.21	Spins	Maybe	Maybe	Much test data available, but little if any operational data	Already allows use of applicable spin parameter data if approved by procuring activity
3.22	Gust Loads	Yes	Yes	Mission analysis procedure of 3.22.2.1.1 can be used. Extrapolation to omega levels needs development	Change 3.22.2 to allow use of mission analysis approach when data enables extreme values to be established.

TABLE XXII

MIL-A-008862A (USAF), 31 March 1971

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
3.1	General				Add statement about use of new method.
3.1.1	Weights	Yes	Yes	Establish design weights from mission profiles or usage data.	
3.1.2	Weight Distribution and CG Positions	No	Yes	Apparently no statistics available. could be developed.	
3.1.3	Engine Thrust	No	Maybe	Difficult to determine probabilities of power settings	
3.1.4	Fixed, Removable and Disposable Mass Items	Yes	Yes	Load factors and weights defined by Landing and Taxi Conditions which may use new method.	
3.2.1	Landing - Loads Analysis	Yes	Yes	Use appropriate sinking speed statistics. Other parameters from mission profiles or usage data.	Paragraph already allows rational analysis acceptable to procuring activity.
3.2.2	Spin-up and Spring-Back Loads	No	Maybe	More realistic data available for Sliding Friction. Touchdown speed definition more difficult.	
3.2.3	Tire Pressure	No	No		
3.2.4	Strut Servicing	No	No		
3.2.5	Wing Lift	No	No		
3.2.6	Overload Landings	Yes	Yes	Combination of sinking speeds and weights for omega conditions shall cover this.	Reasonable limits on omega conditions are probably necessary to avoid unreasonably high energy absorption requirements.

TABLE XXII (Concluded)

MIL-A-008862A (USAF), Concluded

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
3.2.7	Design Limit Sinking Speed	Yes	Yes	Use appropriate sinking speed statistics with weights from mission profiles or usage data.	Probably need to change MIL-T-6053 to recognize new method.
3.2.8	Symmetrical Landings	No	No	Probably cannot develop sufficient data.	
3.2.9	Drift Landing	No	Maybe	Probably cannot define sufficient data to replace this arbitrary requirement.	
3.3	Ground Operation	No	Maybe	Basically use 8862 values, but may use statistical weights, C.G.'s, and speeds	Many of these cases already provide for rational analyses and do not seem to preclude statistical approach (provided introductory paragraphs of 8862 are changed).
3.4	Handling Conditions	No	Maybe	Little data available	
3.5	Miscellaneous	No	Maybe	Doubtful if statistical approach possible.	
3.6	Ski Loads	Yes	Yes	Sinking speeds, weights, etc. can be determined in same manner as for normal landing and handling conditions	

TABLE XXIII

MIL-A-008865A (USAF), 31 March 1971

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
					Doubtful if any of the requirements of MIL-8865A can be replaced by statistical methods. However, statistics may be used to alter individual load or load factor requirements where they indicate that the requirements are irrational for a particular aircraft design or type.

TABLE XXIV

MIL-A-008866A (USAF), 31 March 1971

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
					The present study does not cover fatigue or fail-safe aspects. Therefore, no attempt has been made to determine the influence of the new method on the requirements of MIL-A-8866A.

TABLE XXV

MIL-A-008867A (USAF), 31 March 1971

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
					Statistical methods are not directly applicable to testing. However, since test cases are derived from load cases which may be probabilistic, changes are required to MIL-A-8867A to provide for this option. Only directly affected paragraphs are mentioned. No changes are specified for fatigue tests since such conditions were not included in the study.
3.2.7	Sequence of Tests				Change 7th sentence to: "All tests to design ultimate load (or to factored limit or omega loads where statistical methods are used) shall be completed prior to fail-safe tests and failing-load tests for any condition."
3.4.2	Ultimate Load Tests				Change 1st sentence in same way.
3.4.5.1	Effect of Secondary Internal Loads above Limit Load				Delete "ultimate load" in 1st sentence. Add, after "1.5 times" in 2nd sentence "(or to the appropriate factor for statistically derived conditions)".
3.8	Landing Gear Drop Tests				Change to: "All landing gear drop tests shall be conducted in accordance with MIL-T-6053* except as altered by statistically derived parameters, where applicable."

*MIL-T-6053 shall also be revised to recognize statistical approaches.

TABLE XXVI

MIL-A-8868 (ASG), 18 May 1960

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
					No changes to MIL-A-8868 appear necessary for implementation of the new method.

TABLE XXVII

MIL-A-008869A (USAF), 31 March 1971

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
					The new method does not appear applicable to the requirements of MIL-A-008869A.

TABLE XXVIII

MIL-A-008870A (USAF), 31 March 1971

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
3.1	General				Apparently, the only significant parameters of MIL-A-008870A which might be determined statistically are the maximum speeds ($1.15V_L$ for flutter, etc., and V_L for fail-safe considerations) to be considered. These could be replaced by "extremely improbable" and "extremely remote*" values respectively if sufficient data are available.
3.2.2	Fail-Safe Stability				
3.2.4	External Stress				
4.3.2	Ground Vibration Tests				

*See Section VII for definitions.

TABLE XXIX

MIL-A-8871A (USAF), 1 July 1971

PARA.	SUBJECT	APPLY NEW METHOD		DATA AVAILABILITY	COMMENTS
		NOW	LATER		
					MIL-A-8871A is general enough in most instances that, however design conditions are selected, they are merely flight tested to the same levels. However, some MIL-A-8871A requirements repeat MIL-A-8861 requirements which may be replaced by statistical approaches. These paragraphs are listed below.
[illegible]	Steady-state Yaw Maneuvers				A rudder pedal force of 300 lb. or full rudder deflection may not be applicable if statistical methods are used.
[illegible]	Abrupt Coordinated Rolling Pull-out				The initial load factor may not be 1.0 to 0.8 N_Z if statistics indicate otherwise. This sentence could be deleted with no loss in meaning.
[illegible]	Abrupt Uncoordinated Rolling Pull-out				
[illegible]	[illegible] Maneuvers				These abrupt maneuvers might be shown to be unwarranted by probabilistic analyses.
[illegible]	Asymmetrical Power Simulation Maneuver				The probability of pilot response of such extreme at exactly the wrong time may be statistically extremely improbable.
[illegible]	Deceleration Device Extension Maneuver				Statistics may imply different maximum speeds from V_L for extension of deceleration devices, and might replace V_L itself.

3.4.1 Statistical Methods Where approved statistical methods are used, separate limit and overload (omega) loading conditions and separate limit and overload (omega) factors of safety may be derived using the methods of AFFDL-TR-67-107 and AFFDL-TR-71-178.

3.6 Insert the following after the first sentence·
"Where separate limit and overload (omega) conditions are derived, limit deformation shall be used with limit conditions and overload (omega) deformations shall be used with overload (omega) conditions."

3.11 Insert the following after the first sentence:
"Limit loads and overload (omega) loads shall include applicable factors of safety where statistically determined limit and overload (omega) conditions are used."

3.12c Add the following:
"For statistically derived conditions, allowable factor of safety reductions shall be negotiated with the procuring activity."

6.2.1 Add the following:
"For statistically derived loading conditions, weights may be established probabilistically in combination with other design parameters. Weights higher than the specified maxima shall be considered in statistically establishing overload conditions."

Add: "6.2.2.17 Statistical Methods. For statistically derived loading conditions, speeds may be established probabilistically in combination with other design parameters. Speeds higher than those commensurate with the specified operational use of the airplane shall be considered in statistically establishing overload (omega) conditions."

Add: "6.5 Structural Reliability Goals. Where statistical methods of AFFDL-TR-67-107 or AFFDL-TR-71-178 are used, the occurrence of limit and overload (omega) load levels and minimum structural reliability goals shall be in accordance with Table XXX."

TABLE XXX

STRUCTURAL RELIABILITY OBJECTIVES

Aircraft Type	A, F, TF	O, T, U, B_I, B_{II}, C
Structural Reliability Goal	0.99	0.999
No. Exceedences of Limit Condition per Aircraft Lifetime	10	1
Probability of Exceeding Omega Condition in Aircraft Lifetime	0.01	0.001

c. MIL-A-008861A (USAF) 31 March 1971

3.2 Add:

"Subject to the approval of the procuring activity, the statistical methods of AFFDL-TR-67-107 and AFFDL-TR-71-178 may be used to establish probabilistic combinations of parameters for use in the selection of design conditions."

3.3 Add:

"c. Where sufficient statistical information is available, combinations of weights and load factors may be established probabilistically."

3.14 Add:

"Where statistical methods are used, probabilities of failure may be determined to establish levels of inoperativeness to be used for design conditions."

3.18 Change "design ultimate" to "factored design limit or factored design overload (omega)" in three places.

3.22.2 Add to end of paragraph:

"If sufficient statistics can be established to extend the mission analysis approach to omega load extremes, the maximum loads derived from 3.22.2.1.1 alone may be used to govern the design of the airplane."

3.22.2.1.1 Change the last sentence on page 19 to read:

"The limit loads will be multiplied by 1.5 to establish factored design loads except where statistical methods are used to establish separate limit and overload (omega) loads."

d. <u>MIL-A-008862A (USAF) 31 March 1971</u>

3.1 Add the following:

"Subject to the approval of the procuring activity, the statistical methods of AFFDL-TR-67-107 and AFFDL-TR-71-178 may be used to establish probabilistic combinations of the design parameters of this specification."

3.2.7 Change the last sentence to read:

"The analysis shall be performed in accordance with MIL-T-6053 except as modified by approved statistical methods."

e. <u>MIL-A-008867A (USAF) 31 March 1971</u>

3.2.2 Change seventh sentence to read:

"All tests to design ultimate load (or to limit and omega loads including appropriate test factors of safety for statistically derived conditions) shall be completed prior to performing fail-safe tests and failing-load tests for any condition."

3.4.2 Change first sentence to read:

"Tests to design ultimate load (limit and omega loads including appropriate factors of safety for statistically derived conditions) shall be . . . ."

3.4.5.7 Delete "ultimate-load" in the first sentence. Add the following after "1.5 times" in the second sentence:

"(or to the appropriate factor of safety for statistically derived conditions)"

3.8 Change to read:

"All landing -gear drop tests shall be conducted in accordance with MIL-T-6053 except as altered by statistically derived landing parameters, where applicable."

f. MIL-A-008870A (USAF) 31 March 1971

Add the following at the end of paragraph 3.1:

"Note: Subject to the approval of the procuring activity, the designated speeds V_L and 1.15 V_L of this specification may be replaced by appropriate statistically determined maximum speeds."

g. MIL-A-8871 (USAF) 1 July 1971

No specific changes to MIL-A-8871 are proposed at this time. Possible conflicts with implementation of statistical methods are pointed out in tables XX through XXIX.

14.4 AFSC-DH Series Review

a. Necessary changes to the AFSC-DH series in order to implement the new procedure are quite minor. Basically, the changes involve redefinition of limit-ultimate load concepts rather than use of a 1.5 factor of safety in several handbooks and the inclusion of definitions and reference documents in DH 1-1.

The proposed AFSC DH 1-7, Aerospace Materials, may require some changes but since it has not been issued, it was not reviewed. Proposed changes for the other documents in the series follow.

b. AFSC DH 1-1 (1 December 1970)

Section 2L, page 2. Add the following:

"LOAD, OMEGA - A low probability of occurrence over load level which replaces the ultimate load concept in the application of the statistical approaches of AFFDL-TR-67-107 and AFFDL-TR-71-178."

Section 25, page 1. Add the following to the definition of SAFETY FACTOR:

"In the application of the statistical approaches of AFFDL-TR-67-107 and AFFDL-TR-71-178 limit and overload (omega) conditions may have individual safety factors which are statistically determined."

Chapter 4. Add the following to the list of references:

AFFDL-TR-67-107
AFFDL-TR-71-178

c. AFSC DH 1-6 (Revised 20 January 1971)

Design Note 3BX. Change item 3. to read as follows:

"3. Use an ultimate factor of safety of 1.50 except where acceptable statistical methods are employed to develop separate limit and overload (omega) conditions and corresponding factors of safety."

d. AFSC DH 1-X (Revised 15 January 1971)

Design Note 6A1. Change item 1.2 to read as follows:

"1.2 Use an ultimate factor of safety of 1.50 except where acceptable statistical methods are employed to develop separate limit and overload (omega) condition and corresponding factors of safety."

e. AFSC DH 2-1 (Revised 1 October 1970)

Design Note 2A1. Under paragraph 2. BASIC DESIGN AND TEST PHILOSOPHY, replace the 4th sentence with the following: "Design the aircraft so that it will not fail at ultimate loads (or at limit or omega loads including appropriate factors of safety when statistical methods of AFFDL-TR-67-107 and AFFDL-TR-71-178 are used)."

f. AFSC DH 2-X (15 September 1970)

Design Note 1A1. Change item 1.2 to read as follows:

"1.2 Use an ultimate factor of safety of 1.50 except where acceptable statistical methods are employed to develop separate limit and overload (omega) conditions and corresponding factors of safety."

14.5 MIL-F-8785B Review

a. This section of the study is concerned with establishing the need and availability of appropriate data necessary [illegible]et the existing design requirements of MIL-F-8785B (reference 7) when using the new design method.

The military specification, MIL-F-8785B, contains the requirements for flying qualities of United States military piloted airplanes. The requirements of this specification should be applied to assure that no limitations on flight safety or on the capability to perform intended missions will result from deficiencies in flying qualities. The flying qualities of modern airplanes are the results of in-depth design analyses using current aerodynamic criteria. These flying qualities are then evaluated by pilots flying simulators or the actual airplane. One of the most acceptable evaluation standards for flying qualities is the Cooper Rating System (reference 8).

b. In MIL-F-8785B there exist three levels of flying qualities; i.e., Level 1, Level 2 and Level 3. These levels are very nearly parallel to the standards of the Cooper Rating System. The definition of each of the three levels as specified in MIL-F-8785B is as follows:

Level 1 - Flying qualities clearly adequate for the mission Flight Phase.

Level 2 - Flying qualities adequate to accomplish the mission Flight Phase, but some increase in pilot workload or degradation in mission effectiveness, or both, exists.

Level 3 - Flying qualities such that the airplane can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate, or both. Category A Flight Phases can be terminated safely, and Category B and C Flight Phases can be completed.

c. It is not the intent of this work to regenerate or update the aerodynamic criteria or the flying qualities standards. Rather, it is intended to establish an interface between these criteria-standards and the new design method. This method inherently features the statistical concepts of probability and reliability.

A first round of coalescing these statistical concepts and the flying qualities standards already exists in MIL-F-8785B and in the Concorde flying qualities specification TSS Standard Number 3 (reference 9). In these specifications certain degraded flying quality levels are linked with a probability of occurrence of airplane failure states. No breakdown of the failure states into the various airplane components and systems is attempted.

d. There are numerous aircraft systems, such as flight controls, powerplant, navigation, landing gear and communication systems, each of which has different characteristics relative to probability of failure. Some of these systems directly affect the flying quality level of the airplane. Perhaps the most directly related is the flight control system.

In this study the flight control system of the C-141 MAC Transport has been chosen to illustrate the probabilities of system and sub-system failures. The C-141 flight control system is composed of several subsystems, the major elements of which fall into three groups; basic controls, trim controls and other controls. These major elements are further broken down according to their specific task and they are listed as follows:

Basic Controls:	1. Aileron
	2. Rudder
	3. Elevator
Trim Controls:	1. Roll
	2. Yaw
	3. Pitch
Other Controls:	1. Flap
	2. Spoiler
	3. Stall Prevention

e. Failure rate data have been collected for the C-141 MAC Transport fleet over a period covering the entire flight life of the airplane, which began about mid 1965. A sampling of failure rate data, covering 336,418 flight hours, has been used in this analysis. This data was accumulated between September 1968 and March 1969 and lists failures

of each of the above subsystems. It should be recognized that this data is but a sampling, that the results represent trends and are not conclusive.

The number of in-flight failures and in-flight aborts due to each subsystem of the flight control system have been extracted from a voluminous bank of available data. The probability of failure for the various C-141 sub-systems is presented on Figure 80. Interestingly enough the trim control sub-systems exhibit the lowest probability of failure or the highest reliability. The boundary line shown as Level 2 is taken from section three of MIL-F-8785B. The factor used to convert probability per flight to probability per flight hour is five (the nominal C-141 flight is approximately 5 hours in duration).

Similarly, the number of flight aborts for each sub-system is shown on Figure 81. In this sampling of probability data there were no in-flight aborts attributed to the roll or yaw trim sub-systems. It should be noted that the Level 3 specification from MIL-F-8785B is much more stringent than the Level 2 standard. The scatter of the data indicates that perhaps the specifications should be expanded to cover separately each group of sub-systems such as basic controls, trim controls and others. Up to this point only the flight control system has been discussed. The probability of in-flight aborts due to the C-141 powerplant system for the previously mentioned data sampling is 72.5 aborts per 1000,000 flight hours.

f. Before an actual family of specifications can be recommended, an in-depth study of flight failures and in-flight aborts is necessary. Typical classifications of airplanes should include transports, cargo, fighters, tankers, etc. Military transport and cargo fleets to be analyzed would include the C-141, C-5A, C-130, KC-135 and C-123. Commercial fleets to be examined could include at least the L-188, L-1011, B707, B727, B737, B747, DC-8, DC-9, DC-10, C880 and C990.

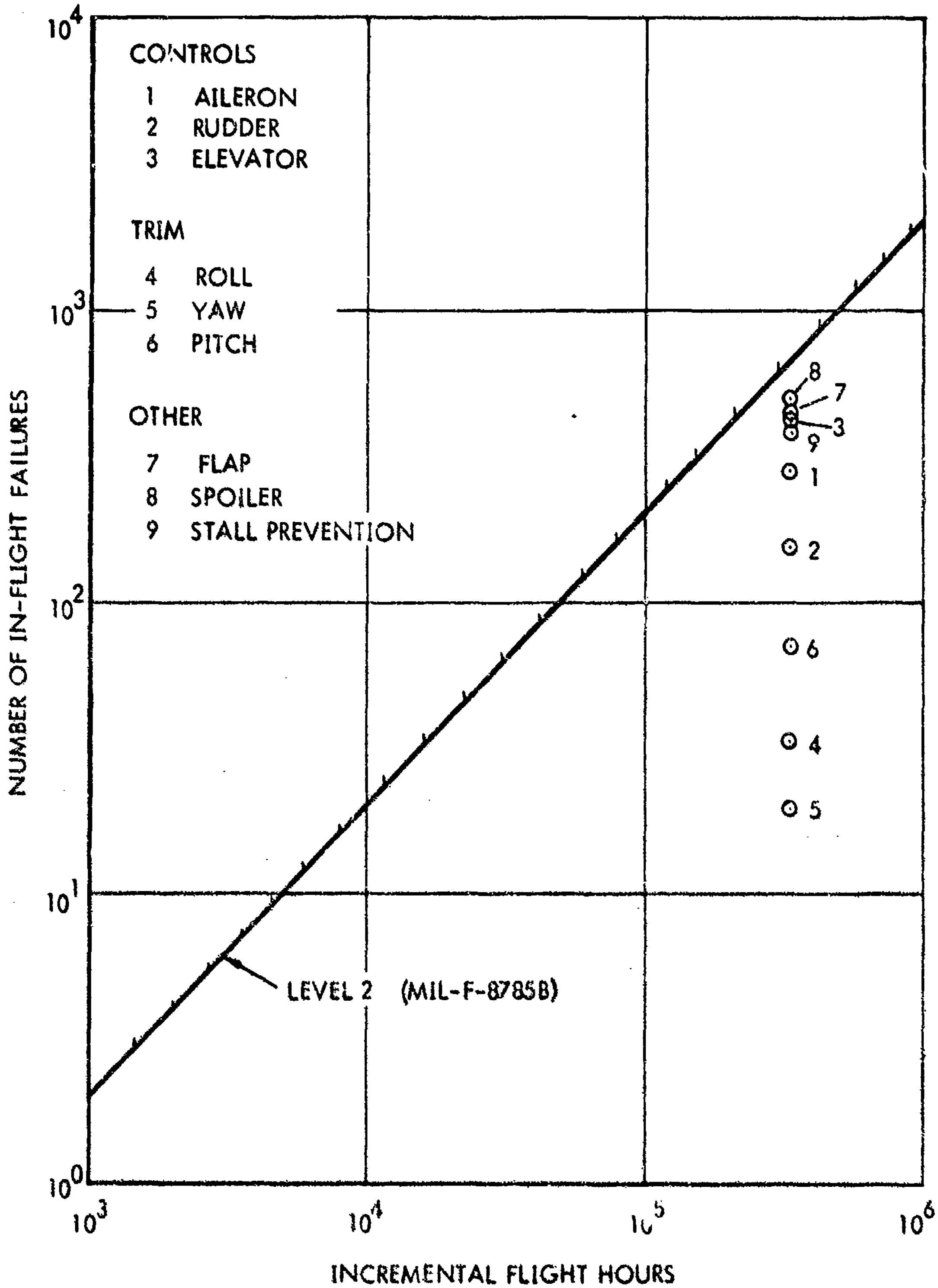


FIGURE 80 C-141 IN-FLIGHT FAILURES (336,418 HOURS)

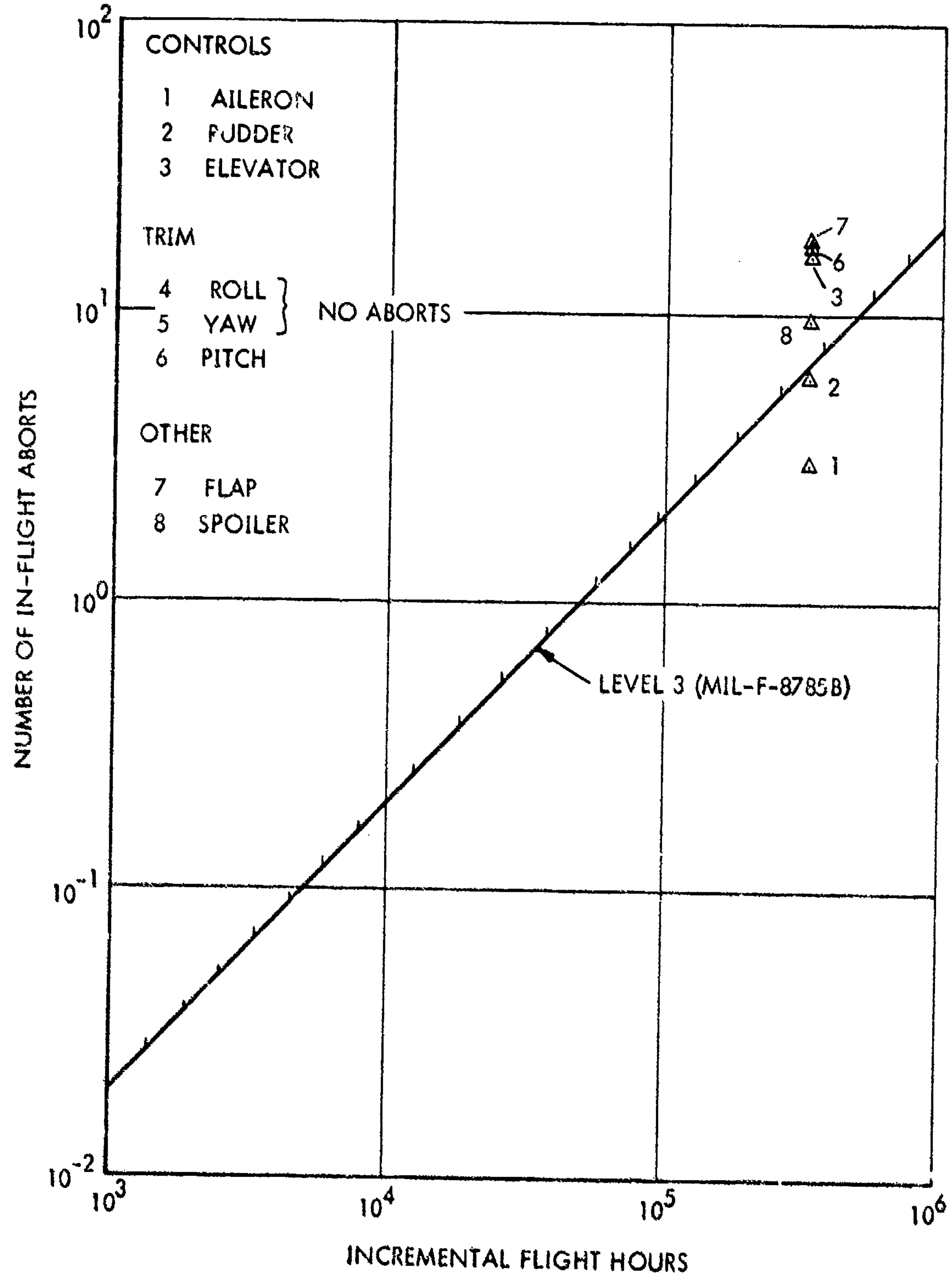


FIGURE 81 C-141 IN-FLIGHT ABORTS (336,418 HOURS)

It is possible that the probability of failure analysis for each classification of airplane could produce a different set of specifications for each. Even within a classification the degree of system and subsystem complexity can produce a wide dispersion of failure probability data. In any event it is proposed that each of these factors be considered in the analysis to aid in the development of a recommended set of specifications.

SECTION XV
CONCLUSION AND RECOMMENDATIONS

15.1 Conclusions

a. The study described in this report has been aimed at securing a more complete understanding of the requirements for and implications of the static strength aspects of the system of probabilistic criteria developed in reference 1. The principal conclusion is that the implementation of the complete system would be premature, but that a partial application can and should be begun.

b. The concept of a single numerical value for the reliability of an airframe (or even for one specific location on that airframe) is superficially attractive, but any real advantage is completely negated by the problems associated with interpretation of the number. Not only must every possible cause of loading be established in probabilistic terms, but every factor affecting the strength must also be established. Unless the total picture is assembled piece by piece, nothing will be known about the relative importance of the various conditions, and nothing will be known about ways of changing the results by modifying the operational instructions or by redesign.

c. Lack of statistical definitions of loading conditions is a major obstacle to implementation of the method. This is most true of asymmetric flight cases and of cases involving combinations of parameters (speed, weight, load condition, load level, etc.) which cannot be regarded as independent.

d. The reliability evaluation depends on comparisons between load and strength, both expressed by a common parameter. The choice of this parameter is complicated by interaction between load systems. For example, if wing root bending moment is the measure of applied load, it must also be the measure of strength; but the allowable bending moment may depend on the applied torsion, shear and internal pressure. Hence the strength definition will generally be more complex than implied by reference 1. A normalized parameter might be used.

e. The need for a single design load remains, as does the concept of design allowable strength. Without the ability to match these values, determination of structural dimensions is impossible. This is recognized in reference 1 and confirmed. However, the design factors to be used will vary with the statistical properties involved.

f. The strength distribution must recognize the variations due to fabrication and assembly processes, as well as those of the basic material. Data on these effects is lacking, and is urgently needed.

g. The probability that the achieved strength levels will not be those intended must be recognized by the inclusion of a suitable "error" function in the analysis. This may be arbitrary or based on appropriate test experience; the choice is relatively insensitive, since the incorporation of test results forms a partially self-compensating process.

h. Testing changes its meaning; it is not a proof of strength, but a means of indicating probable error levels. The test factors used may vary according to the reliability level to be "demonstrated"; design to a high factor followed by testing to a moderate factor

can imply the same total risk as design to a moderate factor with testing to a high factor. The risk of destroying the specimen could enable an optimum overall cost-effectiveness to be achieved.

i. Repeated testing (on independent specimens) will contribute to the overall state of knowledge. Both laboratory tests and actual flight experiences have the same meaning of demonstration of a certain minimum strength.

j. Test failures and tests surviving given loads have different meanings. The former are difficult to interpret consistently, and a test failure should be regarded as a test surviving a slightly lower load.

k. Two sets of design conditions require evaluation. One is aimed at ensuring negligible risk of a sample where strength is less than the loads expected within the placard limits. The second is aimed at providing a suitable margin of strength for moderate excesses over placard limits, but a lower reliability will be defined for these "omega" conditions. Different design factors and different test factors may be used for limit and omega conditions.

l. Management decisions will be required which will be based on unfamiliar information. It is important that the physical implications of the various mathematical operations are maintained to ensure that such decisions are correctly guided. Compromises between reliability levels, design loads and factors, between limit and omega conditions, between weight and reliability, and between design and test conditions will be necessary. Assessment of the relative importance of structural and non-structural systems will be required in order to achieve the requisite total reliability at minimum cost.

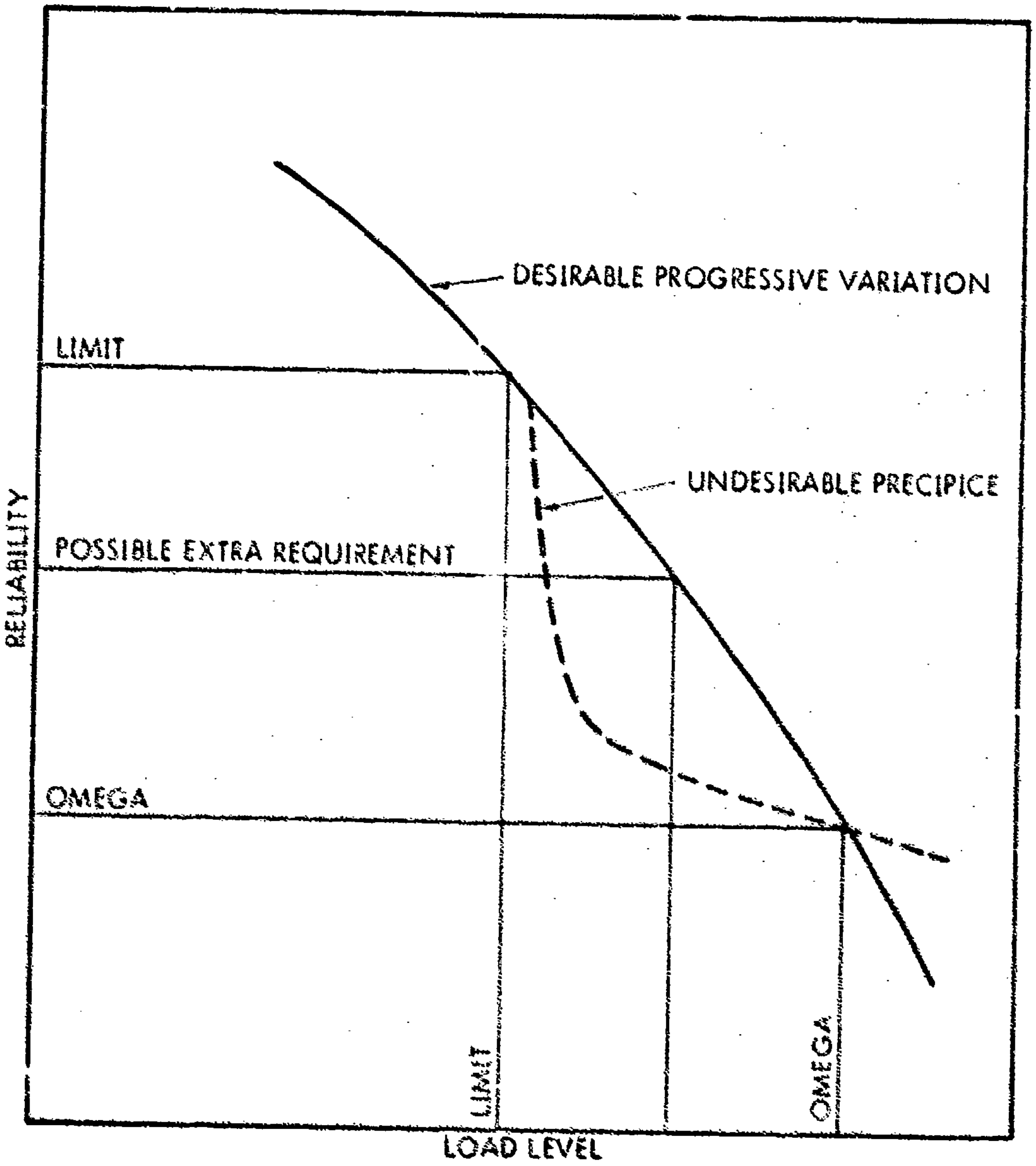


FIGURE 82 DESIRABLE VARIATION FROM LIMIT CONDITION TO OMEGA CONDITION

m. The operation of the vehicle must be controllable in order that the intended reliability levels are achieved. This will require selection of placard limits which reflect the significant parameters, but which remain practical; this area requires considerable care. Subsystem behavior may assume a greater importance than hitherto.

n. The initial use of the method for relative reliability studies will lead to the necessary acquisition of familiarity with the techniques and will provide guides to the factors and reliability levels implied by the present criteria; gradual re-evaluation will lead to more efficient structures by permitting identification of structural location and flight conditions which are potentially of greater risk.

o Continuous updating of the evaluations is required to reflect the increased knowledge of each stage of the design and operation of a vehicle.

p. The choice of only two levels (limit and omega) at which the reliability goals are defined may not always be adequate to give the desirable progressive reduction in reliability. For example, increasing the temperature between limit and omega conditions could result in the onset of "thermal buckling" just above limit condition and a sudden reduction in allowable load. Further increases might have little change, leading to a "reliability precipice" of the type shown in Figure 82. It may be necessary to examine at least one condition between limit and omega conditions to ensure the avoidance of such phenomena. The "high proof" condition of reference 17 is an example of this type of precaution.

15.2 Recommendations

a. Familiarity with the proposed system must be gained; it is recommended that a series of studies be initiated which evaluate the relative reliability levels of specific aircraft and structural locations for different loading cases, and of different locations for the same loading cases. The incompleteness of available data is less important in this process, since a reasonably constant error will have little influence on the relative reliabilities.

b. During this phase, attempts must be made to collect and analyze data which is presently lacking. This includes statistical definitions of the load systems and of the strength of fabricated structures. Analysis of large samples of existing (but relatively inaccessible) test data will permit selection of better error functions than those so far proposed.

c. The statistical equations used to represent distributions of loads and strength should be examined to ensure that the important "tails" are not required. Skewed distributions and double-family distributions should be investigated.

d. The development of the appropriate terminology is vital to the understanding of the analysis, to the achievement of the correct decisions for compromises and for the selection of operational guides which ensure that the intended reliability is achieved. This new terminology must recognize fully the changed meaning of testing; the term "ultimate load" should be discontinued and replaced by "factored load"; the factor may be a design factor or a test factor and the load may be a limit load or an overload (omega load).

e. Initial application of the proposed method to a new design should either

1) retain the 1.5 design factor on limit loads and vary the test factor according to the number of tests, the strength and load dispersions, the error function and the desired reliability, or

2) use equal values of design and test factor, the value being varied with the same parameters.

The reliability goals should be based on those implied by the present criteria, to ensure no abrupt change in the structural integrity as the new method is incorporated.

f. Specifications and handbooks should be modified to permit the use of probabilistic methods as an option to the present methods where sufficient data exists.

g. The influence of subsystems on the structural loads requires evaluation of the rates of many different types of failure. Acquisition of the necessary data should be encouraged.

h. Interactions between static strength, fail-safe strength (the residual strength of a damaged structure) and fatigue "strength" require identification. Studies of the nature of these interactions should be pursued to permit the whole spectrum of structural reliability to be expressed in a consistent manner.

APPENDIX I

A NOTE ON THE USE OF DOUBLE-FAMILY DISTRIBUTIONS

A1.1 It is frequently necessary to assume that all of the observations in a sample are members of a single homogenous population whose distribution follows one or other of the many standard forms (normal, log-normal, Weibull, Gumbel, Poisson, Pearson, etc.). Such an assumption will often give a good representation of the observed probabilities of occurrence, particularly in the neighborhood of the mode (the most frequent values). For many purposes, a best fit in this region is desirable, but there are other applications of statistical distributions where other factors require emphasis.

The structural reliability problem is such a realm. The major difference from the more common reliability analyses is that the "mean time to failure" is not the desired measure of structural reliability. It is the risk of first failure that is required, since the ultimate goal is the prevention of all failures (in effect, there is no acceptable failure rate). The implications are to throw much more emphasis on the unusually high loads and the unusually low strengths, which in turn demands that the statistical representations match the appropriate tails of the distributions rather than the regions near the mode.

A1.2 In practice, there is no strict logic behind the assumption that all members of a sample set of observations belong to a single family, unless it can be verified that only one independent parameter is involved, and this is seldom if ever possible. Furthermore, the information necessary to divide the data into its component families will not generally be available. Empirical methods provide a means by which the essential analysis can be performed: the aim is simply to provide a mathematical model of the population which is adequate in the region of most importance.

A1.3 The use of double-family distributions is not new; power-spectral analyses have habitually employed such methods, and the representation of loads and strength data by two Gaussian distributions is described in reference 10. The suggestion that the maneuver loads spectrum may contain members of two distributions is also mentioned in reference 11. This appendix expands the approach on a more formal basis and suggests methods by which an acceptable empirical distribution may be derived. No attempt need be made to ascertain the reasons why two families (or more) are involved.

The examples are based on the use of the first asymptotic theory of extremes (Gumbel distribution, see references 12, 13, and 14) but the principles are applicable to any basic distribution. Gumbel's equations are simple and permit the easy formation of the required quantities within a computer program.

A1.4 Let the basic distribution be such that the probability of a value less than X is P, where P is a function of X, of the mean ($\bar{X}$) and the standard deviation (S) together with appropriate constants. In order to determine the values of the constants, one viable technique is to transform the probabilities (P) into a new variable, Y, by means of a transcendental equation which results in a linear relationship between Y and X. A least squares best fit can then be used to match the fitted line to the transformed observed probabilities. The pattern of the deviations is then used as a guide to the choice of parameters for the two families used to achieve the desired representation.

In the case of the Gumbel distribution, the basic equation is:

$$P = \exp\left(-\exp(-Y)\right) \qquad \text{A1-1}$$

where:

$$Y = A\,\frac{X-\bar{X}}{S} + B \qquad \text{A1-2}$$

$$A = \pi/\sqrt{6} = 1.28255 \text{ and } B = 0.57722$$

and the transcendental equation is

$$Y' = -\log_e\left(-\log_e P\right) \qquad \text{A1-3}$$

A1.5 A series of N observations (see Table XXXI) is arranged in ascending order of X, each term being allotted a rank, m, which ranges from 1 for the lowest to N for the highest. To avoid the mathematical dilemma associated with a probability of one, the actual observed probabilities ($\frac{m}{N}$) are replaced arbitrarily by $m/N+1$ in the usual manner. These values of $m/N+1$ are transformed to observed values of Y', using equation A1-3 and plotted against

TABLE XXXI

DATA FOR DOUBLE-FAMILY EXAMPLE

X	m	$\frac{m}{N+1}$	Y
240	1	.0417	-1.16
241	2	.0833	-.91
243	3	.1250	-.73
243	4	.1667	-.58
244	5	.2083	-.45
245	6	.2500	-.33
245	7	.2917	-.21
247	8	.3333	-.09
248	9	.3750	.02
248	10	.4167	.13
252	11	.4583	.25
252	12	.5000	.37
253	13	.5417	.49
256	14	.5833	.62
256	15	.6250	.76
258	17	.7083	1.07
259	18	.7500	1.25
260	19	.7917	1.45
261	20	.8333	1.70
264	21	.8750	2.01
266	22	.9167	2.44
275	23 = N	.9583	3.16

$X = 252.7$

$S = 8.80$

$v = S/_X = 0.0348$

as shown in figure 83. The best straight line can then be determined by an appropriate least squares error method (reference 32 describes a suitable technique which minimizes both the x- and y- errors). It will be realized that plotting the transformed probabilities on linear paper is simply equivalent to plotting the real probabilities on the appropriate probability paper, and for illustrative purposes, figure 84 shows the same data on normal probability paper.

A1.6 It will be noticed that the observations deviate from the fitted line in an ordered, rather than a random manner, which suggests that the assumed distribution is not valid. Now experience indicates that each of the single basic distributions plots as a line with single curvature (or of course, as a straight line); it is also apparent that the data follow a reflex curve with a point of contraflexure. The usual arguments as to the importance of the single highest observation will apply, of course, and if so desired, this point may be omitted from the best fit process. Even when this is done, the reflex-curve pattern remains.

A1.7 Now let the assumption be made that the data comprise representatives of two families. Let these have means and standard deviations $\bar{X}_A$, $\bar{X}_B$, S_A and S_B respectively. Also, let R_B of the total population be contained in family B, so that family A contains $(1-R_B)$ of the total. The resultant probability of a value less than X can now be expressed as

$$P_T = (1-R_B)\,P_A + R_B\,P_B \qquad \text{A1-4}$$

where $$P_A = \exp(-\exp(-Y_A))$$

and $$P_B = \exp(-\exp(Y_B)) \qquad \text{A1-5}$$

represent the independent probabilities of a value less than X in the separate distributions, where

$$Y_A = A\,\frac{x - \bar{x}_A}{S_A} + B$$

$$Y_B = A\,\frac{x - \bar{x}_B}{S_B} + B \qquad \text{A1-6}$$

The transcendental equation to derive the transformed probability, Y_T, is then

$$Y_T = -\log e\,(-\log e\,(P_T)) \qquad \text{A1-7}$$

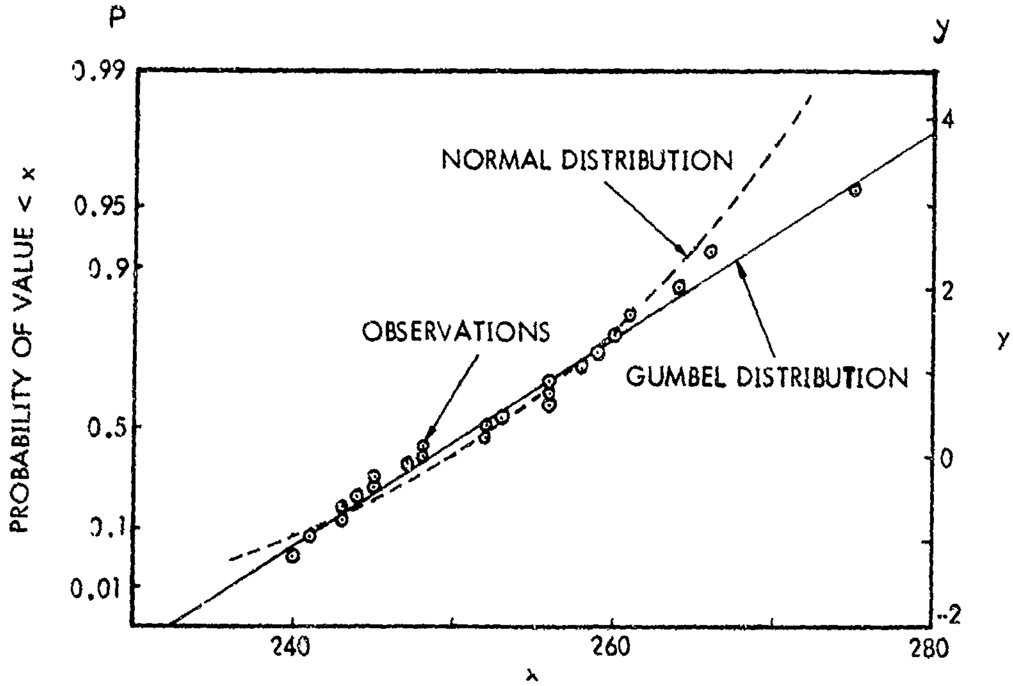


FIGURE 83. OBSERVED AND FITTED DISTRIBUTIONS (GUMBEL PAPER)

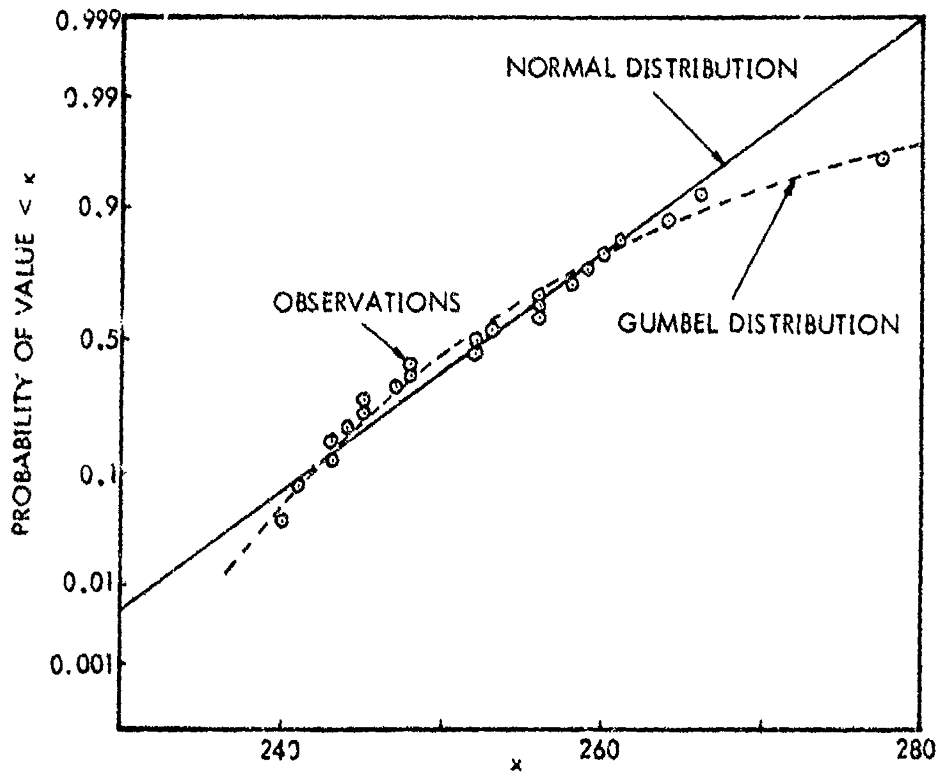


FIGURE 84. OBSERVED AND FITTED DISTRIBUTIONS (NORMAL PROBABILITY PAPER)

Figures 85 through 90 show the implied distributions in conventional form.

It is convenient to use the standard coefficients A and B for both distributions, rather than to vary these; no significant degradation should occur in practice, although it would be more correct to vary the coefficients according to the amounts of data allotted to the two separate distributions.

A1.8 The remaining problem is to determine the five basic parameters $\overline{X}_A$, S_A, R_B, $\overline{X}_B$ and S_B. Automated trial and error methods are feasible, but simpler methods can be devised which are generally satisfactory. These depend on appropriate assumptions as to the location of the mean of the B-family and the nature of the overlap. The observed data are alloted to suitable intervals and simple rules formulated for allocating the entire contents of a band to family B at the upper end of the range, allocating the entire contents to family A at the lower end of the range, and for arbitrary division between the families for a few bands close to the assumed $\overline{X}_B$. Lockheed-Georgia Company has a program of this type which generally provides good results, or which serve as a starting point for a limited improvement by trial and error. Once the observations are allotted to the two families, each can be fitted by its best straight line and the compound distribution can be generated from equations A1-5 and A1-4.

Figures 91 through 93 show a worked example, using the data of Table XXXI. The improved fit to the observations will be seen.

A1.9 The foregoing discussion relates to the case where the distribution is skewed to the upper level of X. For the opposite skewness, the simplest way of handling the Gumbel equations is to change the sign of X in the computations (the derivation of a minimum value of +X is equivalent to the derivation of a maximum value of -X).

A1.10 It is also interesting to note that some observed distributions can be better fitted by a compound distribution obtained by subtracting family B from family A. Such an approach may have validity in strength estimation, a possible physical explanation being that the total population consists of several overlapping distributions whose sum is close to a single-family distribution; quality control processes then remove one particular sub-family.

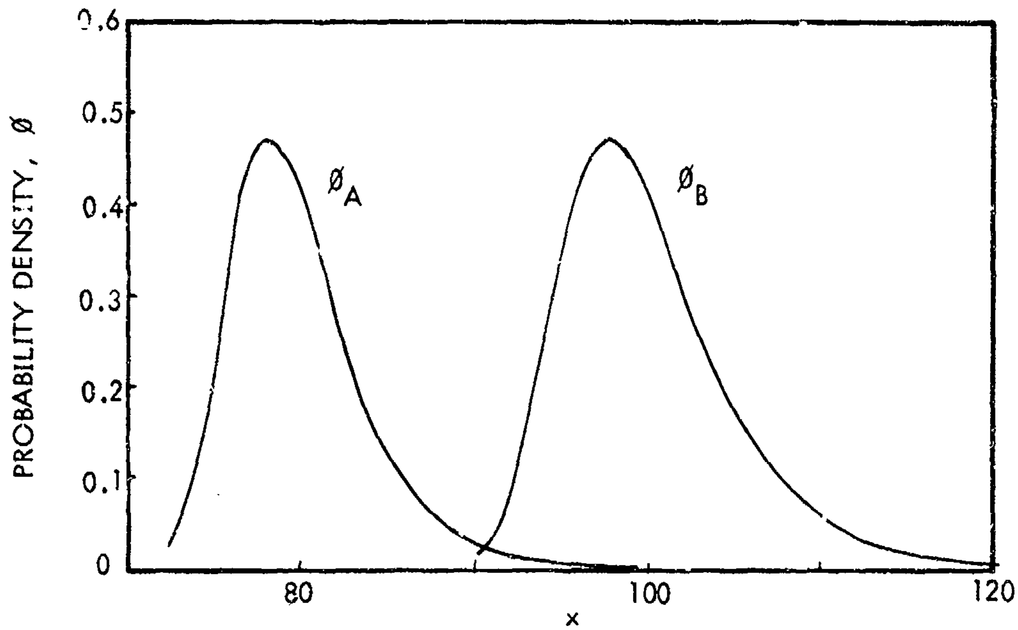


FIGURE 85. INDEPENDENT DISTRIBUTIONS OF THE TWO FAMILIES

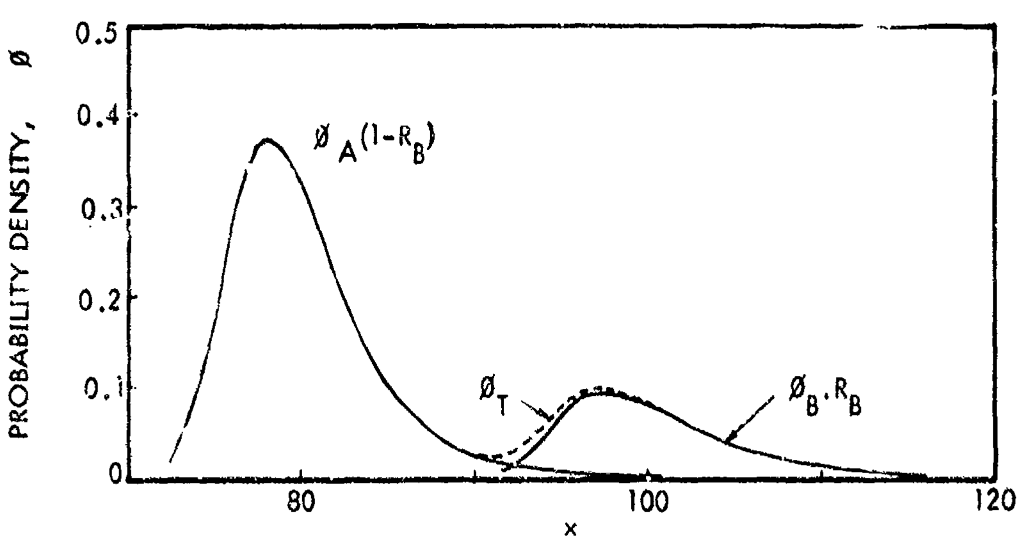


FIGURE 86. RESULTANT DISTRIBUTION OF THE DOUBLE FAMILY

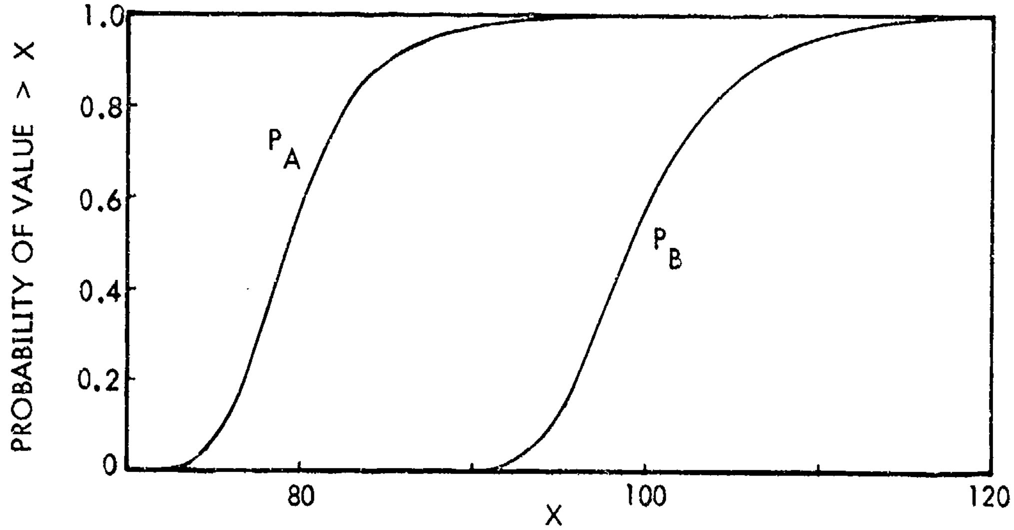


FIGURE 87. INDEPENDENT CUMULATIVE PROBABILITIES OF THE TWO FAMILIES (LINEAR SCALE)

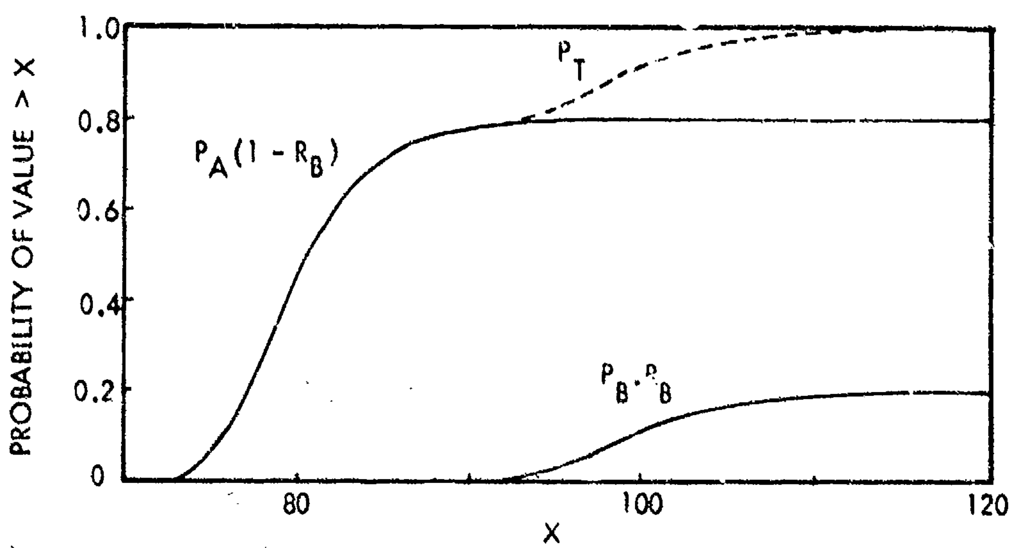


FIGURE 88. RESULTANT CUMULATIVE PROBABILITY OF THE DOUBLE FAMILY (LINEAR SCALE)

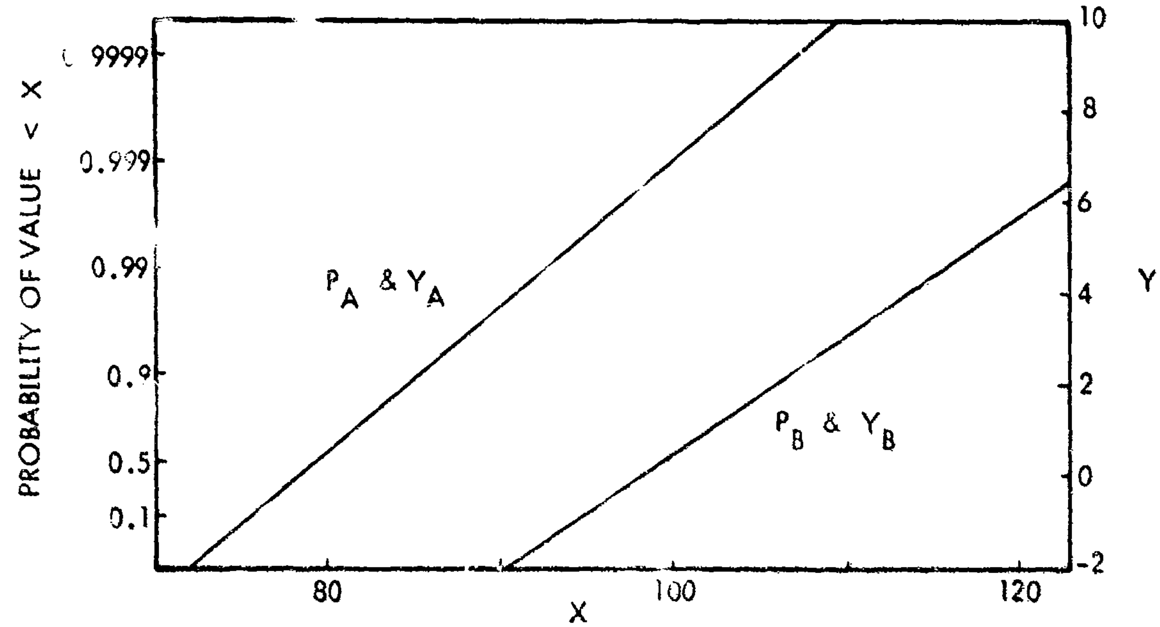


FIGURE 89. INDEPENDENT CUMULATIVE PROBABILITIES OF THE TWO FAMILIES (GUMBEL PAPER)

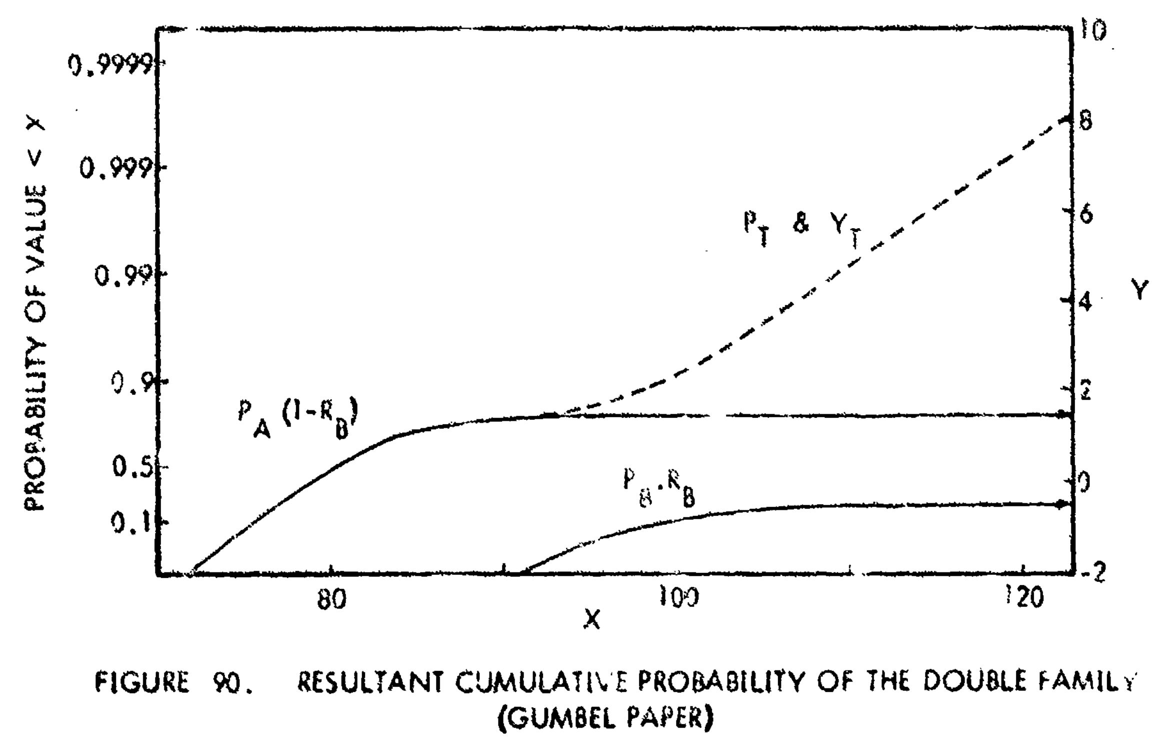


FIGURE 90. RESULTANT CUMULATIVE PROBABILITY OF THE DOUBLE FAMILY (GUMBEL PAPER)

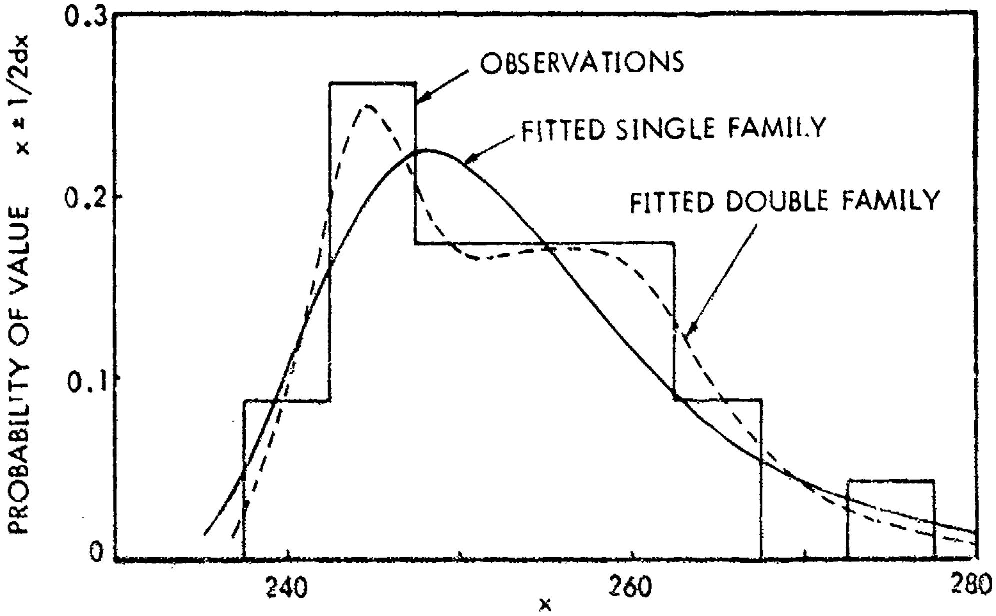


FIGURE 91. FREQUENCY DISTRIBUTION FOR DOUBLE-FAMILY EXAMPLE

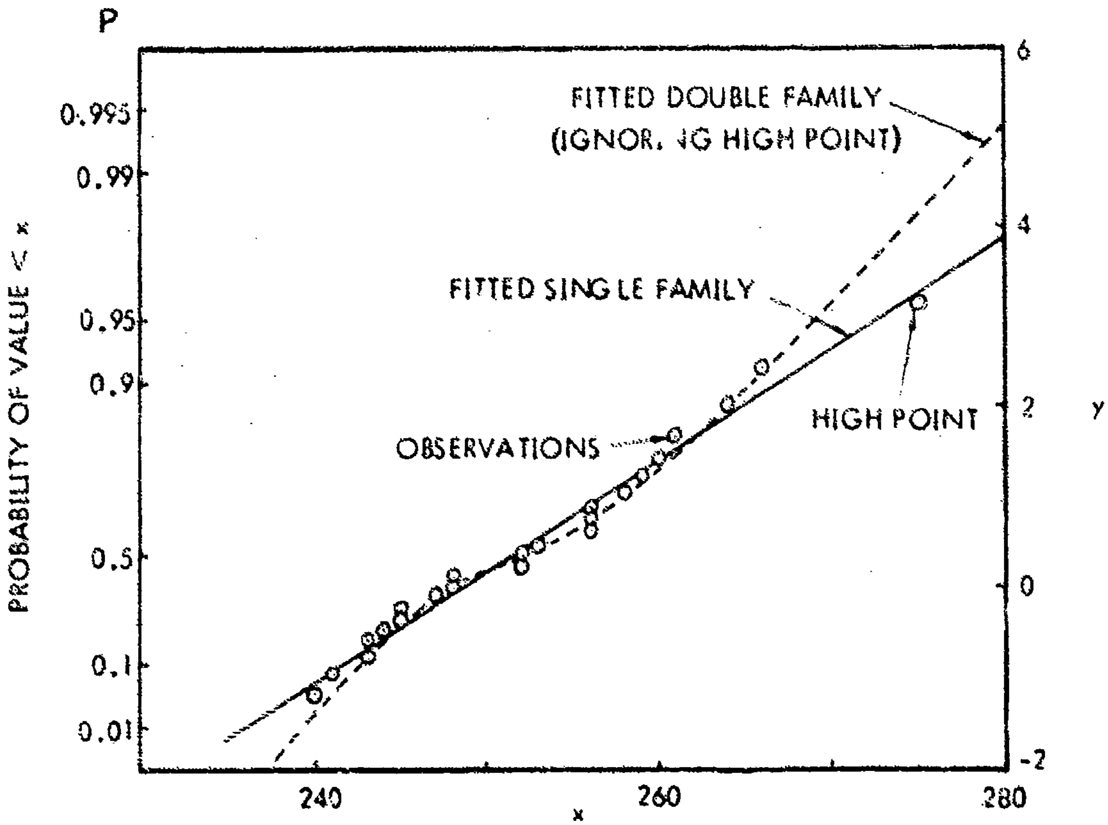


FIGURE 92. CUMULATIVE PROBABILITY FOR DOUBLE-FAMILY EXAMPLE (GUMBEL PAPER)

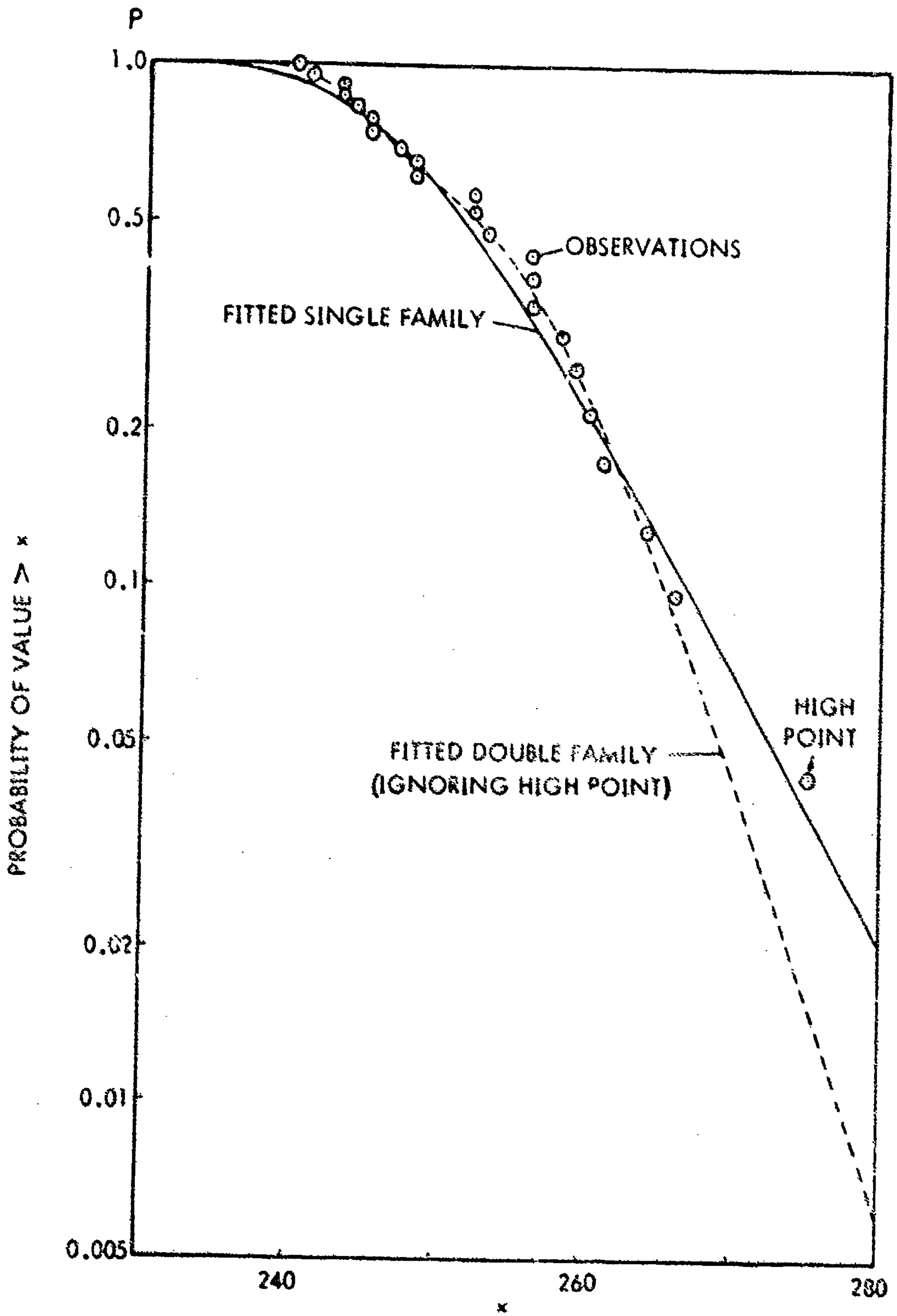


FIGURE 93. CUMULATIVE PROBABILITY FOR DOUBLE-FAMILY EXAMPLE (LOGARITHMIC PAPER)

Whatever the explanation, the results, inasmuch as they provide a good empirical curve-fit can be held to be as justified as the common assumption that the population is describable by a single Gaussian distribution. An example of this negative second family approach is shown in Figures 94 and 95.

AI-11 For reference purposes, Tables XXXII and XXXIII contain values of the transformed variable, Y, corresponding to various values of the probability of a lesser value (F) and of a greater value (P).

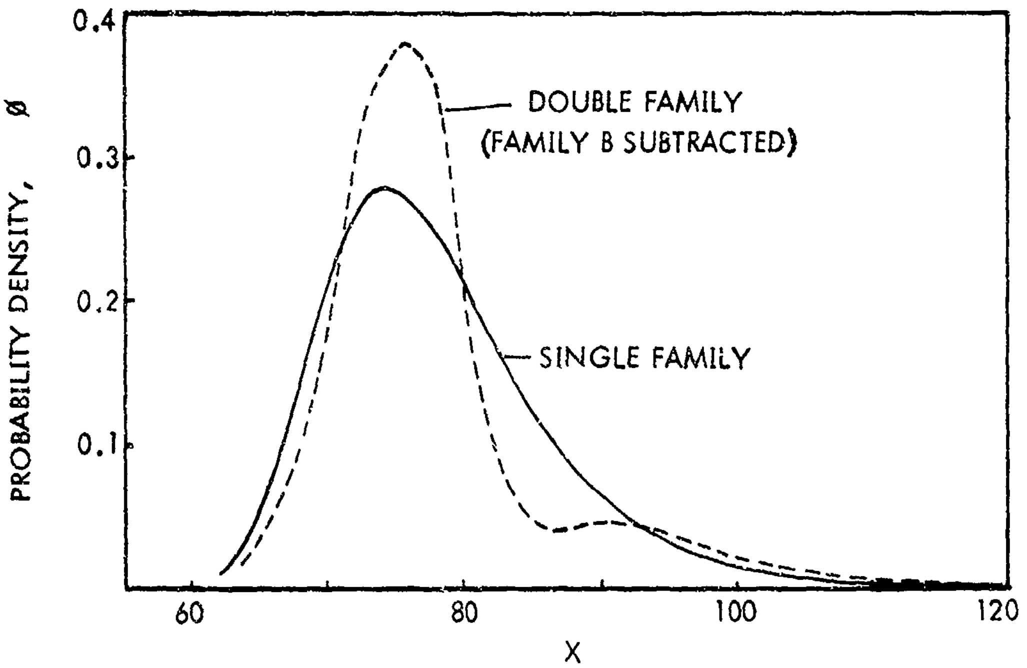


FIGURE 94. FREQUENCY DISTRIBUTION WITH FAMILY B SUBTRACTED

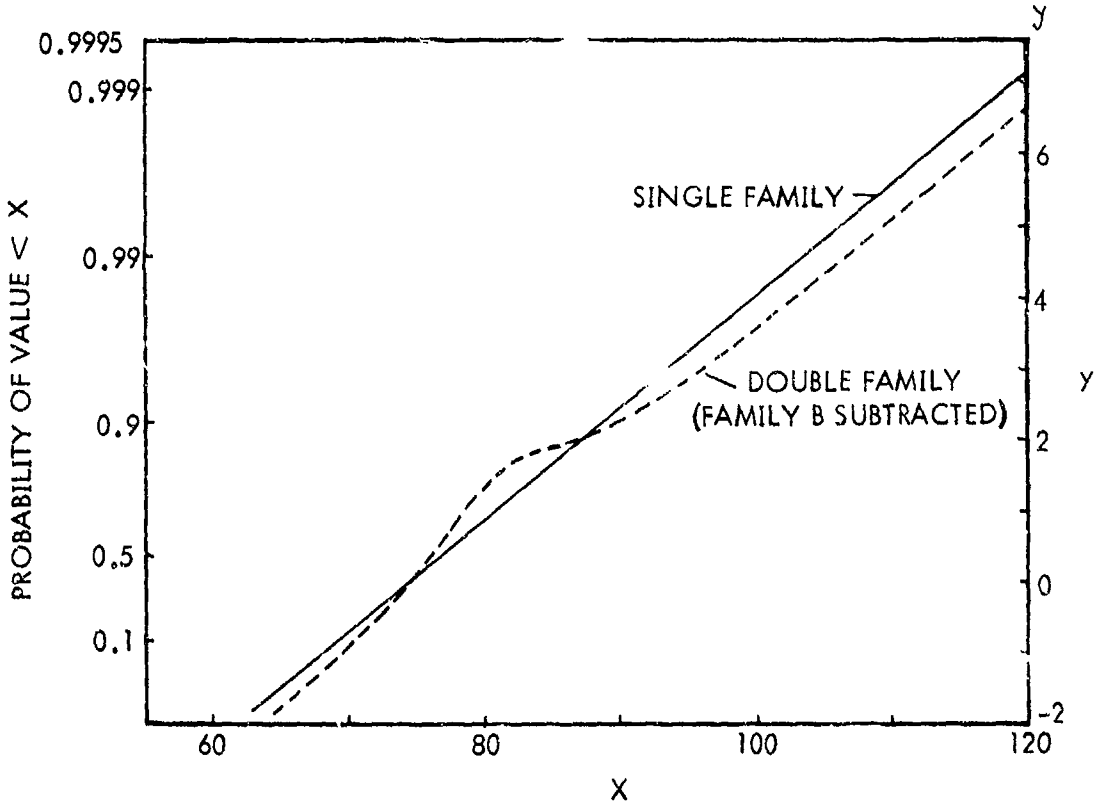


FIGURE 95. CUMULATIVE PROBABILITY WITH FAMILY B SUBTRACTED (GUMBEL PAPER)

TABLE XXXII

ORDINATES OF GUMBEL EXTREME-VALUE PAPER

P	F	Y	P	F	Y
.99990000	.00010000	-2.220	.00030000	.99970000	8.112
.99950000	.00050000	-2.028	.00020000	.99980000	8.517
.99900000	.00100000	-1.933	.00015000	.99985000	8.805
.99500000	.00500000	-1.667	.00010000	.99990000	9.210
.99000000	.01000000	-1.527	.00009000	.99991000	9.316
.98000000	.02000000	-1.364	.00008000	.99992000	9.433
.95000000	.05000000	-1.097	.00007000	.99993000	9.567
.90000000	.10000000	-.834	.00006000	.99994000	9.721
.80000000	.20000000	-.476	.00005000	.99995000	9.903
.70000000	.30000000	-.186	.00004000	.99996000	10.127
.60000000	.40000000	.087	.00003000	.99997000	10.414
.50000000	.50000000	.367	.00002000	.99998000	10.820
.40000000	.60000000	.672	.00001500	.99998500	11.107
.30000000	.70000000	1.031	.00001000	.99999000	11.513
.20000000	.80000000	1.500	.00000900	.99999100	11.618
.15000000	.85000000	1.817	.00000800	.99999200	11.736
.10000000	.90000000	2.250	.00000700	.99999300	11.870
.09000000	.91000000	2.361	.00000600	.99999400	12.024
.08000000	.92000000	2.484	.00000500	.99999500	12.206
.07000000	.93000000	2.623	.00000400	.99999600	12.429
.06000000	.94000000	2.783	.00000300	.99999700	12.717
.05000000	.95000000	2.970	.00000200	.99999800	13.122
.04000000	.96000000	3.199	.00000150	.99999850	13.410
.03000000	.97000000	3.491	.00000100	.99999900	13.816
.02000000	.98000000	3.902	.00000090	.99999910	13.921
.01500000	.98500000	4.192	.00000080	.99999920	14.039
.01000000	.99000000	4.600	.00000070	.99999930	14.172
.00900000	.99100000	4.706	.00000060	.99999940	14.326
.00800000	.99200000	4.824	.00000050	.99999950	14.509
.00700000	.99300000	4.958	.00000040	.99999960	14.732
.00600000	.99400000	5.113	.00000030	.99999970	15.019
.00500000	.99500000	5.296	.00000020	.99999980	15.425
.00400000	.99600000	5.519	.00000015	.99999985	15.713
.00300000	.99700000	5.808	.00000010	.99999990	16.118
.00200000	.99800000	6.214	.00000009	.99999991	16.223
.00150000	.99850000	6.502	.00000008	.99999992	16.341
.00100000	.99900000	6.907	.00000007	.99999993	16.475
.00090000	.99910000	7.013	.00000006	.99999994	16.629
.00080000	.99920000	7.130	.00000005	.99999995	16.811
.00070000	.99930000	7.264	.00000004	.99999996	17.034
.00060000	.99940000	7.418	.00000003	.99999997	17.322
.00050000	.99950000	7.601	.00000002	.99999998	17.728
.00040000	.99960000	7.824	.00000001	.99999999	18.015

TABLE XXXIII

GUMBEL EXTREME-VALUE FUNCTIONS

Y	F	P	Y	F	P
-3.00	.000000002	.999999998	2.00	.873423018	.126576982
-2.90	.000000013	.999999987	2.10	.884744450	.115255550
-2.80	.000000072	.999999928	2.20	.895114921	.104885079
-2.70	.000000345	.999999655	2.30	.904603235	.095396765
-2.60	.000001422	.999998578	2.40	.913275257	.086724743
-2.50	.000005119	.999994881	2.50	.921193652	.078806348
-2.40	.000016319	.999983681	2.60	.928417653	.071582347
-2.30	.000046587	.999953413	2.70	.935003020	.064996980
-2.20	.000120361	.999879639	2.80	.941001952	.058998048
-2.10	.000284104	.999715896	2.90	.946463160	.053536840
-2.00	.000617979	.999382021	3.00	.951431982	.048568018
-1.90	.001248398	.998751602	3.10	.955950439	.044049561
-1.80	.002358693	.997641307	3.20	.960057393	.039942607
-1.70	.004194641	.995805359	3.30	.963788725	.036211275
-1.60	.007061961	.992938039	3.40	.967177466	.032822534
-1.50	.011314287	.988685713	3.50	.970253907	.029746093
-1.40	.017352013	.982647987	3.60	.973046184	.026953816
-1.30	.025494394	.974505606	3.70	.975579590	.024420410
-1.20	.036148603	.963851397	3.80	.977877595	.022122405
-1.10	.049580083	.950419917	3.90	.979961574	.020038426
-1.00	.065988031	.934011969	4.00	.981851064	.018148936
-.90	.085463607	.914536393	4.10	.983563825	.016436175
-.80	.108008977	.891991023	4.20	.985116288	.014883712
-.70	.133486792	.866513208	4.30	.986523069	.013476931
-.60	.161682807	.838317193	4.40	.987797215	.012202785
-.50	.192295637	.807704363	4.50	.988952473	.011047527
-.40	.224961793	.775038207	4.60	.989998505	.010001495
-.30	.259276859	.740723141	4.70	.990945950	.009054050
-.20	.294816315	.705183685	4.80	.991804419	.008195581
-.10	.331154272	.668845728	4.90	.992581069	.007418931
-.00	.367879428	.632120572	5.00	.993284095	.006715905
.10	.404607657	.595392343	5.10	.993921794	.006078206
.20	.440991025	.559008975	5.20	.994498618	.005501382
.30	.476723686	.523276314	5.30	.995020837	.004979163
.40	.511544824	.488455176	5.40	.995493598	.004506402
.50	.545239203	.454760797	5.50	.995921500	.004078500
.60	.577635825	.422364175	5.60	.996308960	.003691040
.70	.608605310	.391394690	5.70	.996659622	.003340378
.80	.638056159	.361943841	5.80	.996977016	.003022984
.90	.665930696	.334069304	5.90	.997264296	.002735704
1.00	.692200631	.307799369	6.00	.997524314	.002475686
1.10	.716862589	.283137411	6.10	.997759640	.002240360
1.20	.739934050	.260065950	6.20	.997972623	.002027377
1.30	.761449218	.238550782	6.30	.998165376	.001834624
1.40	.781455476	.218544524	6.40	.998339817	.001660183
1.50	.800010711	.199989289	6.50	.998497680	.001502320
1.60	.817179479	.182820521	6.60	.998640552	.001359448
1.70	.833031744	.166968256	6.70	.998769842	.001230158
1.80	.847640313	.152359687	6.80	.998886839	.001113161
1.90	.861079343	.138920657	6.90	.998992719	.001007281

TABLE XXXIII (CONCLUDED)

GUMBEL EXTREME-VALUE FUNCTIONS

Y	F	P	Y	F	P
7.00	.99908[illegible]526	.000911474	12.00	.9[illegible]3840	.0[illegible]6154
7.10	.999175228	.000824772	12.10	.9[illegible]34	.0[illegible]
7.20	.999253683	.000746317	12.20	.9[illegible]4963	.0[illegible]5037
7.30	.999324679	.000675321	12.30	.9[illegible]54[illegible]0	.0[illegible]4560
7.40	.999388926	.000611074	12.40	.9[illegible]5872	.0[illegible]4128
7.50	.999447063	.000552937	12.50	.9[illegible]6267	.0[illegible]37[illegible]
7.60	.999499664	.000500336	12.60	.9[illegible]17	.00000[illegible]83
7.70	.999547265	.000452735	12.70	.9[illegible]6945	.0[illegible]3055
7.80	.999590345	.000409655	12.80	.9[illegible]723[illegible]	.0[illegible]2764
7.90	.999629319	.000370681	12.90	.9[illegible]7497	.0[illegible]2503
8.00	.999664590	.000335410	13.00	.9[illegible]7	.00000[illegible]
8.10	.999696501	.000303499	13.10	.9[illegible]	.0[illegible]2049
8.20	.999726379	.000273621	13.20	.[illegible]814[illegible]	.0[illegible]18[illegible]
8.30	.999751508	.000248492	13.30	.[illegible]8316	.0[illegible]
8.40	.999775149	.000224851	13.40	.9[illegible]	.0[illegible]15[illegible]
8.50	.999796547	.000203453	13.50	.9[illegible]	.0[illegible]137[illegible]
8.60	.999815904	.000184096	13.60	.9[illegible]87[illegible]	.0[illegible]124[illegible]
8.70	.99983[illegible]	.000166[illegible]	13.70	.[illegible]	.[illegible]
8.80	.999849275	.000150725	13.80	.9[illegible]	.0[illegible]
8.90	.999863610	.000136390	13.90	.[illegible]	.0[illegible]92[illegible]
9.00	.999876589	.00012341[illegible]	14.00	.9[illegible]158	.0[illegible]842
9.10	.99988[illegible]	.000[illegible]	14.20	.9[illegible]	.0[illegible]
9.20	.9[illegible]	.0[illegible]	14.40	.[illegible]	.0[illegible]
9.30	.9[illegible]80574	.0[illegible]91420	14.60	.[illegible]	.0[illegible]
9.40	.9[illegible]17269	.0[illegible]82731	14.80	.[illegible]	.0[illegible]37[illegible]
9.50	.9[illegible]2514[illegible]	.0[illegible]74856	15.00	.[illegible]	.0[illegible]
9.60	.9[illegible]	.[illegible]	15.20	.[illegible]	.[illegible]
9.70	.9[illegible]	.[illegible]	15.40	.[illegible]	.[illegible]
9.80	.9[illegible]	.0[illegible]	15.60	.[illegible]	.[illegible]
9.90	.9[illegible]9920	.0[illegible]50180	15.80	.[illegible]	.[illegible]
10.00	.9[illegible]	.0[illegible]	16.00	.[illegible]	.[illegible]
10.10	.9[illegible]58917	.0[illegible]	16.20	.[illegible]	.[illegible]
10.20	.9[illegible]628[illegible]	.0[illegible]3717[illegible]	16.40	.[illegible]	.[illegible]
10.30	.9[illegible]	.0[illegible]	16.60	.[illegible]	.[illegible]
10.40	.9[illegible]	.0[illegible]	16.80	.[illegible]	.[illegible]
10.50	.9[illegible]	.0[illegible]	17.00	.[illegible]	.[illegible]
10.60	.9[illegible]	.0[illegible]	17.20	.[illegible]	.[illegible]
10.70	.9[illegible]	.0[illegible]	17.40	.[illegible]	.[illegible]
10.80	.9[illegible]79593	.0[illegible]	17.60	.[illegible]	.[illegible]23
10.90	.9[illegible]81537	.0[illegible]18463	17.80	.[illegible]81	.[illegible]
11.00	.9[illegible]	.0[illegible]	18.00	.[illegible]	.[illegible]
11.10	.9[illegible]	.0[illegible]	18.20	.[illegible]	.[illegible]12
11.20	.9[illegible]321	.0[illegible]	18.40	.[illegible]	.[illegible]
11.30	.9[illegible]17	.0[illegible]12383	18.60	.[illegible]	.[illegible]
11.40	.9[illegible]	.0[illegible]	18.80	.[illegible]	.[illegible]7
11.50	.9[illegible]	.0[illegible]	19.00	.[illegible]	.[illegible]
11.60	.9[illegible]	.0[illegible]9172	19.20	.[illegible]	.[illegible]
11.70	.9[illegible]	.0[illegible]	19.40	.[illegible]	.[illegible]
11.80	.9[illegible]2490	.0[illegible]7510	19.60	.[illegible]7	.[illegible]3
11.90	.9[illegible]3205	.0[illegible]795	19.80	.[illegible]7	.[illegible]3

APPENDIX II

BASIC EQUATIONS OF MODIFIED COMPUTER PROGRAM

A2-1 Introduction

A description of the program used for the present study is given in Appendix III and examples are shown in Appendix IV. Two reasons exist for the use of a program different from that in reference 1. The study necessitated gaining a full understanding of the practical implications of each step in the procedure, and the program of reference 1 possesses certain shortcomings in the extent to which the intermediate results are presented. The second reason was a desire to determine the degree to which a given company could utilize statistical programs already developed; the Lockheed-Georgia Company had an operational program for applying Gumbel distributions in both single and double-family form (references 13 and 14), and the incorporation of these was thought desirable. Combining these reasons, it was evidently easier to write a new program than to add to the original program of reference 1, although the latter was used as a basis.

A2-2 Loads Spectrum

a. Two alternative methods are provided for the definition of the load probability; the required form is in terms of the probability of a load exceeding x_i, where x_i is a band-edge.

b. Analysis of operational data, by the theory of extremes, provides a suitable data base using a minimum of information. If each observation is the maximum load in a given recording period (preferably a constant period, such as 1000 hours), then the distribution of such extremes is expected to follow an exponential law of which Gumbel's equation is one example. Reference 12 contains a full description of the theory. This distribution of maximum extremes is typically skewed with the tail towards higher values, and its use in the present context is suggested in reference 11 among other sources.

Now the resulting distribution defines the probability ($p_{x_{L_i}}$) that the maximum load expected to occur per 1000 hours (or whatever period is used) is between x_i and x_i+dx, in other words, $p_{x_{L_i}}$ is the probability that any load level up to ($x_i + \frac{1}{2}$dx) will occur. The resultant probability (P_{x_i}) of each load (x_i) is then given by:

$$P_{x_{L_i}} = \sum_{i=N}^{i} p_{x_{L_i}} \qquad \text{A2-1}$$

as shown in figure 96.

The distribution p_{x_i} is defined in terms of the five basic parameters of the double-family distribution as described in Appendix I. The cumulative probability of a value less than x_i is

$$P_{x_i} = \exp(-\exp(-y_A)) \cdot (1 - R_B) + \exp(-\exp(-y_B) \cdot R_B \qquad \text{A2-2}$$

$$\left.\begin{aligned} \text{where} \qquad y_A &= 1.28255 \frac{x_i - \bar{x}_A}{s_A} + 0.57722 \\ \text{and} \qquad y_B &= 1.28255 \frac{x_i - \bar{x}_B}{s_B} + 0.57722 \end{aligned}\right\} \qquad \text{A2-3}$$

when written in terms of the means and standard deviations of the two families, where, if the coefficients of variation are defined:

$$\left.\begin{aligned} s_A &= \bar{x}_A \cdot v_A \\ s_B &= \bar{x}_B \cdot v_B \end{aligned}\right\} \qquad \text{A2-4}$$

If the intercepts and slopes of the best-fit straight lines on Gumbel paper are known, equations A2-3 can be rewritten as

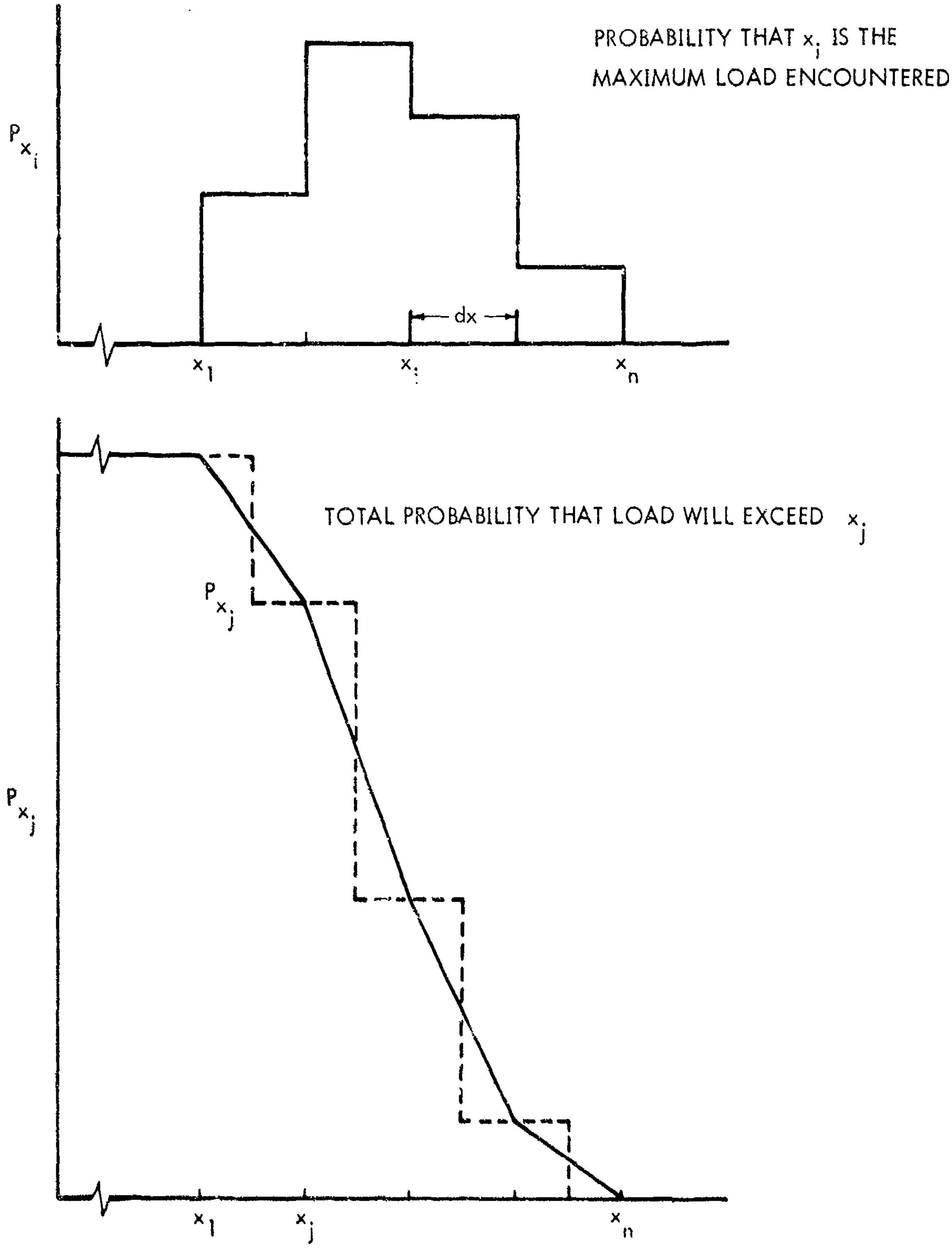


FIGURE 96. LOAD SPECTRUM USING DISTRIBUTION OF EXTREMES

$$y_A = \frac{x_i - x_{int_A}}{s_A}$$

$$y_B = \frac{x_i - x_{int_B}}{s_B} \qquad \text{A2-5}$$

where $x_{int_A} = \bar{x}_A - 0.57722\,\beta_A$

$x_{int_B} = \bar{x}_B - 0.57722\,\beta_B$ A2-6

and $\beta_A = S_A/1.28255 = \bar{x}_A \cdot v_A/1.28255$

$\beta_B = S_B/1.28255 = \bar{x}_B \cdot v_B/1.28255$

The cumulative probability ($P_{x_{i+}}$) of a value less than (x_i+dx) is similarly calculated, and the required probability ($p_{x_{L_i}}$) of a value in the band x_i, x_i+dx is found from the difference of the two cumulative probabilities.

A2.3 Strength Distribution

a. Material Strength:

The basic properties of the material strength distribution are again input in the form described in Appendix I, but the theory of minimum extremes is employed, which implies a distribution with the tail towards lower strengths; this was found to be representative of actual data samples examined (see Appendix V) and emphasizes the importance of the exceptionally weak specimens.

The cumulative probability of a value greater than ($x_i + \frac{1}{2}$ dx) is

$$P_{x_{i+}} = \exp(-\exp(-y_A)) \cdot (1 - R_B) + \exp(-\exp(-y_B)) \cdot R_B \qquad \text{A2.7}$$

$$y_A = 1.28255\left(\frac{\bar{x}_A - x_i - \frac{1}{2}dx}{s_A}\right) + 0.57722$$

$$y_B = 1.28255\left(\frac{\bar{x}_B - x_i - \frac{1}{2}dx}{s_B}\right) + 0.57722 \qquad \text{A2.8}$$

where the two equations above define y_A and y_B.

The cumulative probability ($P_{x_{i-}}$) of a value greater than ($x_i - \frac{1}{2}dx$) is similarly defined, and the required probability ($p_{x_{s_i}}$) of a value in the band $x_i \pm \frac{1}{2}dx$ is calculated as the difference between the two cumulative probabilities. When the whole distribution is defined, its overall mean ($\bar{x}_s$) and coefficient of variation ($v_s = s_A/\bar{x}_s$) can be found by summation of first and second moments in the usual way.

b. Fabrication Variation:

The available material strength data above may need modification to recognize a secondary variation due to fabrication or assembly processes. This variation is treated as if it were a definition of the distribution of the mean strength of the material. Let L_{x_i} be the probability of a mean strength in the interval $x_i \pm \frac{1}{2}dx$, where the equations for L_{x_i} are parallel to those in the previous paragraph. The basic material distribution shape is applied to the fraction of the total population which has its mean at x_i (the $\pm \frac{1}{2}dx$ range is ignored and the sample assumed to occur at x_i).

The two families are scaled so that this fraction of the total population is formed from distributions with means of

$$\bar{x}_{A_i} = \bar{x}_A \cdot \frac{x_i}{\bar{x}_s}$$

$$\bar{x}_{B_i} = \bar{x}_B \cdot \frac{x_i}{\bar{x}_s} \qquad \text{A2.9}$$

and with the original coefficients of variation, v_A and v_B, giving standard deviations of

$$\left.\begin{aligned} s_{A_i} &= \bar{x}_{A_i} \cdot v_A \\ s_{B_i} &= \bar{x}_{B_i} \cdot v_B \end{aligned}\right\} \qquad \text{A2.10}$$

The double family distribution resulting from these values is multiplied by the probability of its occurrence, namely L_{x_i}, thus yielding the contribution, δp_{x_i}, to the total probability of a strength $x_i \pm \frac{1}{2} dx$.

Summation of contributions due to all of the mean strength values gives the resultant strength distribution,

$$px_{s_i} = \sum_{i=1}^{N} \left(\delta p_{x_i} \right)_{\bar{x}=x_i} \qquad \text{A2.11}$$

and summation of the first and second moments enables the overall mean strength and coefficient of variation to be found.

If the secondary effect of the fabrication is not needed, this step is simply omitted.

c. Where the strength distribution is only required as a means of determining the characteristic shape, and not the absolute strength level, the units used may be chosen independently of the units used for defining the loads. The necessary scaling is performed in later steps.

A2.4 Intended Strength

a. The selected unfactored design load, which may be either a limit condition or an omega condition, is used as a basis for determining the intended strength to result from the structural sizing procedure. The design factor of safety, FS, is first applied to give the factored design load:

$$FACLD = FS \times UNFLD \tag{A2.12}$$

and any design margin of safety then incorporated in the estimation of the (factored) design load for the present case

$$PDSNLD = FACLD\,(1 + MS) \tag{A2.13}$$

b. At this point, it is necessary to consider the influence of conditions previously examined, for the case being currently analyzed may not be a design case.

If the previously critical design load, DSNLD, is greater than the present value, PDSNLD the former is used in all subsequent steps. If the new value, PDSNLD, exceeds the previous value, it replaces DSNLD.

The strength levels implied by other structural constraints such as stiffness or fatigue, are incorporated in the same way, an appropriate value of DSNLD being input.

c. Once the critical design load, DSNLD, is established, it is related to the design allowable strength, expressed as S_{all}, a number of standard deviations below the intended mean strength. If the conventional 'A' value is being used, this will be roughly 2.33 (assuming the strength distribution is normal). It therefore follows that

$$DSNLD = AMSTR\,(1 - S_{all} \cdot V_S) \tag{A2.14}$$

where AMSTR is the intended mean strength

V_S is the coefficient of variation of the strength distribution.

Hence

$$AMSTR = DSNLD/(1 - S_{all} \cdot V_S) \tag{A2.15}$$

which defines the intended mean strength of the total production run of the part being analyzed.

d. Now the equations of section A2.3 define the distribution of a population whose mean is at $\bar{x}_s$. The actual mean is intended to be at AMSTR, and the intended distribution of strength of the individuals in the production run is obtained by repeating these steps with $\bar{x}_A$ and $\bar{x}_B$ values replaced by

$$\bar{x}_A \cdot \text{AMSTR}/\bar{x}_s$$

and

$$\bar{x}_B \cdot \text{AMSTR}/\bar{x}_s$$

respectively.

A2.5 Intended Reliability

a. With the strength distribution resulting from the previous paragraph, the probability that the strength lies in the interval $x \pm \frac{1}{2} dx$ is known as $p_{x_{s_i}}$. A structure having this strength will fail if the load exceeds x_i (this is not strictly true, as it will not fail at load x_i if the strength is in the upper half of the interval; however, this necessary approximation introduces negligible errors if the interval size, dx, is not too large). The probability that the load exceeds x_i is already known to be $P_{x_{L_i}}$, hence the probability of failure, which represents the simultaneous occurrence of these two events, is

$$\delta P_{F_i} = p_{x_{s_i}} \cdot P_{x_{L_i}} \qquad \text{A2.16}$$

b. Integration over the whole range of strength yields the total risk of failure

$$P_F = \sum_{i=1}^{N} \delta P_{F_i} \qquad \text{A2.17}$$

and the reliability is the complement of this, namely

$$R = 1 - P_F \qquad \text{A2.18}$$

c. One simplification can be made for computation: If the strength distribution is summed to give the probability, $P_{R_{s_i}}$, that the strength is less than x_i:

$$P_{R_{s_i}} = \sum_{i=1}^{i} P_{x_{s_i}} \qquad \text{A2.19}$$

then up to the highest load level for which $P_{x_{L_i}} = 1.0$, the failure probability can be expressed in one step as

$$P_{F_i} = P_{R_{s_i}} \cdot 1.0 \qquad \text{A2.20}$$

and integration can be started at this level.

d. The significance of the δP_F values and of the cumulative integration of P_F are of some interest. The distribution of δP_F indicates the density distribution of the risk of failure and can show whether a greater gain in reliability could be achieved by operational restrictions or by deliberately modifying the strength distribution. A peak at low x-values indicates that the very weak specimens ("certain" to fail because of the high probability of the load) contribute most of the total risk. A peak at high x-values indicates that the rare high loads are the major cause of the total risk. In the former case, little gain would result from elimination of high load levels, but in the latter case the benefits would be greater.

A2.6 Probable Discrepancy

a. The probability that a discrepancy may exist between the intended strength and the actual strength of the design is next incorporated. Algebraically, this is performed by means of an assumed distribution of achieved mean strength, $p_{s_{M_i}}$. The program of Appendix III contains four alternative functions suitable for this purpose.

b. Bouton/Jablecki Function:

Reference 1 describes the equation used to represent the test data accumulated by Jablecki from tests performed during the 1940 decade (reference

3). The equation represents a linear variation of the cumulative probability of failure with the ratio of achieved load to intended ultimate strength, both being plotted on logarithmic paper. The program of reference 1 locates the upper end of the line at a point with a cumulative probability of 1.0 when the load ratio is 1.185, and in the "standard" case, locates the lower end at 0.01 probability when the load ratio is 0.333. Other levels are defined by varying the probability of failure at this same load level of 0.333 (figure 97).

The present program retains the same general function, but permits the input of any two points on the straight line. The maximum cumulative probability is truncated at 1.0. The resulting equation is then used to generate the probability than the mean strength lies in each of the intervals $x_i \pm \frac{1}{2} dx$. The equations used are as follows:

Let PF_1 be the given probability of failure below load PPU_1
and PF_2 be the given probability of failure below load PPU_2
then the general probability of failure, PF, below load PPU is given by

$$\frac{\log_{10} PPU - \log_{10} PPU_1}{\log_{10} PPU_2 - \log_{10} PPU_1} = \frac{\log_{10} PF - \log_{10} PF_1}{\log_{10} PF_2 - \log_{10} PF_1} \qquad \text{A2.21}$$

whence $$\log_{10} PF = RI \left|\log_{10} PPU - \log_{10} A\right| \qquad \text{A2.22}$$

where $$RI = \frac{\log_{10} PF_2 - \log_{10} PF_1}{\log_{10} PPU_2 - \log_{10} PPU_1} \qquad \text{A2.23}$$

and $$\log_{10} A = \frac{\log_{10} PF_2 \log_{10} PPU_1 - \log_{10} PF_1 \log_{10} PPU_2}{\log_{10} PF_2 - \log_{10} PF_1}$$

or $$A = 10^{\left\{\frac{\log_{10} PF_2 \log_{10} PPU_1 - \log_{10} PF_1 \log_{10} PPU_2}{\log_{10} PF_2 - \log_{10} PF_1}\right\}} \qquad \text{A2.24}$$

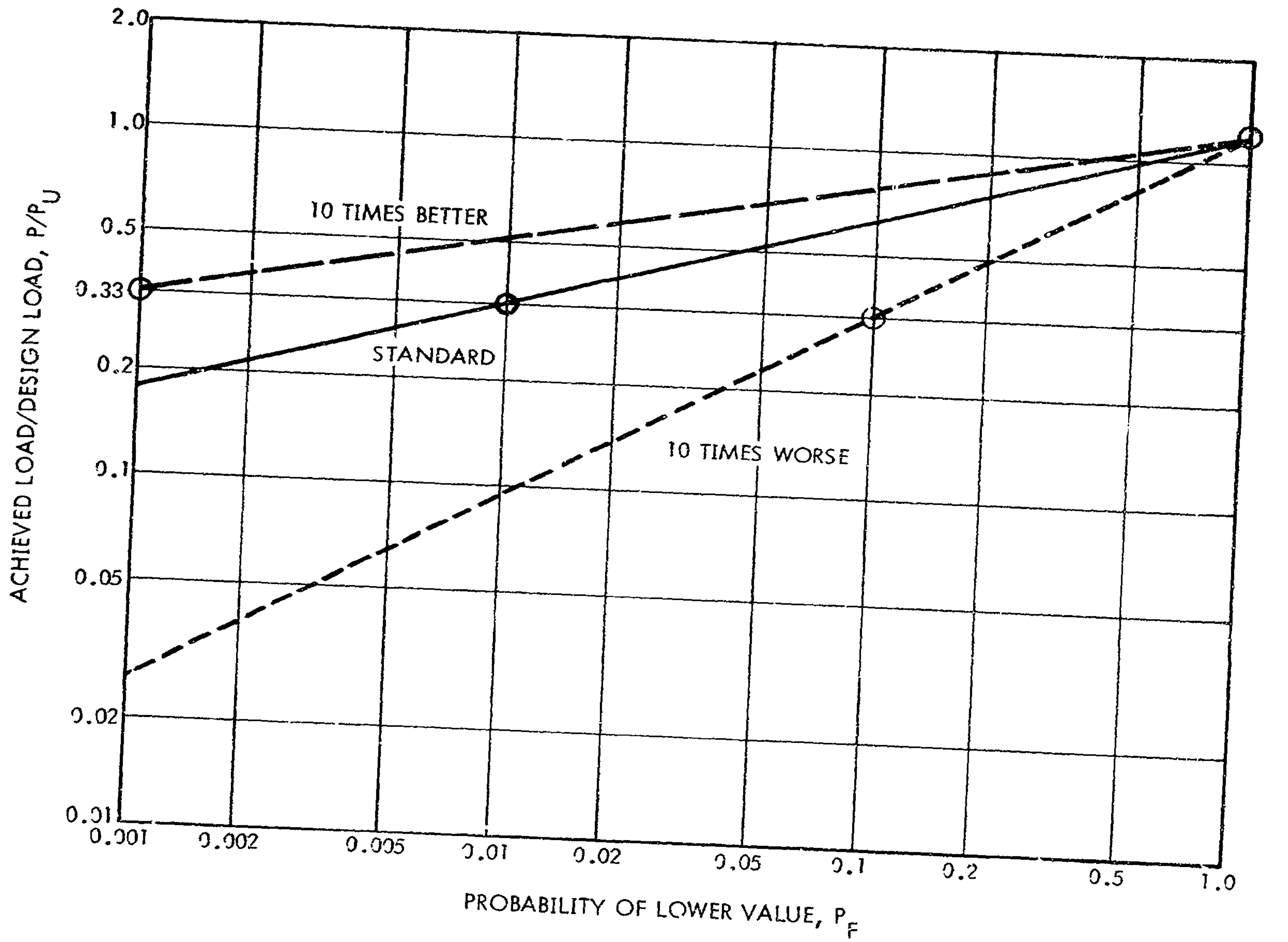


FIGURE 97. BOUTON/JABLECKI ERROR FUNCTION

hence $$\log_{10} PF = \log_{10} \left(\frac{PPU}{A}\right)^{RI}$$

or $$PF = \left(\frac{PPU}{A}\right)^{RI} \qquad \text{A2.25}$$

The fraction of the total mean strength distribution lying in the interval $x_i \pm \frac{1}{2} dx$ is then found from the difference of the cumulative probabilities at the two band edges, substituting $\frac{x - \frac{1}{2} dx}{DSNLD}$ and $\frac{x + \frac{1}{2} dx}{DSNLD}$ in turn for PPU in equation A2.25 with A and RI determined from equations A2.24 and A2.23, respectively. The resulting differences give the required values of $p_{S_{M_i}}$ for each interval.

c. Freudenthal Function:

The expression used is a general form of the equation on figure 3 of reference 4:

$$P_S = \exp\left(-\frac{PPU}{A}\right)^{RI} \qquad \text{A2.26}$$

where P_S is the probability of exceeding a mean strength/design strength ratio, PPU. The corresponding probability of a lower value is

$$PF = 1 - \exp\left(-\frac{PPU}{A}\right)^{RI} \qquad \text{A2.27}$$

As with the Jablecki function, the present program enables the constants to be derived from two known values of PF and PPU. At the two given points,

$$\left.\begin{aligned} PF_1 &= 1 - \exp\left(-\frac{PPU_1}{A}\right)^{RI} \\ PF_2 &= 1 - \exp\left(-\frac{PPU_2}{A}\right)^{RI} \end{aligned}\right\} \qquad \text{A2.28}$$

whence

$$\left(\frac{PPU_1}{A}\right)^{RI} = -\log_e(1 - PF_1)$$

$$\left(\frac{PPU_2}{A}\right)^{RI} = -\log_e(1 - PF_2)$$

or

$$\left.\begin{aligned} RI(\log_{10} PPU_1 - \log_{10} A) &= \log_{10}(-\log_e(1 - PF_1)) \\ RI(\log_{10} PPU_2 - \log_{10} A) &= \log_{10}(-\log_e(1 - PF_2)) \end{aligned}\right\} \qquad A2.29$$

Solving for RI yields

$$RI = \frac{\log_{10}(-\log_e(1 - PF_2)) - \log_{10}(-\log_e(1 - PF_1))}{\log_{10} PPU_2 - \log_{10} PPU_1} \qquad A2.30$$

and subst uting for A gives

$$A = PPU_1/(-\log_e(1 - PF_1))^{1/RI} \qquad A2.31$$

The particular system routine for calculating logarithms prevents zero or unity being chosen as input values of PF or PPU.

The procedure for evaluating the values of $p_{S_{M_i}}$ is identical to that previously described.

d. Gumbel Function:

The process is essentially the same as the above, but the Gumbel distribution function of minimum extremes is used to fit a line through the two input points which are defined as before. At the two given points, the probabilities of lower values are

$$\left.\begin{aligned} PF_1 &= 1 - \exp(-\exp(-y_1)) \\ PF_2 &= 1 - \exp(-\exp(-y_2)) \end{aligned}\right. \qquad A2.32$$

where

$$y_1 = A\,\frac{\overline{PPU} - PPU_1}{S} + B$$

$$y_2 = A\,\frac{\overline{PPU} - PPU_2}{S} + B \qquad \text{A2-33}$$

where $A = 1.28255$

$B = 0.57722$

$\overline{PPU}$ is the mean of the implied distribution and S is the standard deviation.

Now $$A_1 = A\,\frac{PPU_1 - \overline{PPU}}{S} - B = \log_e(-\log_e(1 - PF_1)) \qquad \text{A2.34}$$

and $$A_2 = A\,\frac{PPU_2 - \overline{PPU}}{S} - B = \log_e(-\log_e(1 - PF_2))$$

whence

$$\overline{PPU} = \frac{(A_1 + B)PPU_2 - (A_2 + B)PPU_1}{A_1 - A_2} \qquad \text{A2.35}$$

and

$$S = \frac{A_1 + B}{A(PPU_1 - \overline{PPU})} \qquad \text{A2.36}$$

The calculation of the distribution of mean strengths, $p_{S_{M_i}}$, is then as follows:

The probability of a value greater than $x_i - \frac{1}{2}dx$ will be

$$PR_1 = \exp(-\exp(-y_1)) \qquad \text{A2.37}$$

where $$y_1 = \frac{1.28255}{S}\left(\overline{PPU} - \frac{x_i + \frac{1}{2}dx}{DSFJUD}\right) + 0.57722$$

and the probability of a value greater than $x_i + \frac{1}{2}dx$ will be

$$PR_2 = \exp(-\exp(-y_2)) \qquad \text{A2.38}$$

where $$y_2 = \frac{1.28255}{S}\left(\overline{PPU} - \frac{x_i + \frac{1}{2}dx}{DSNLD}\right) + 0.57722$$

so that the required population in the interval $x_i \pm \frac{1}{2}dx$ is

$$p_{S_{M_i}} = PR_1 - PR_2 \qquad \text{A2.39}$$

e. Double-Family Gumbel Distribution:

The fourth error function permits the use of the more general double-family distribution defined by the means of the two families, the standard deviations (these are assumed equal in this application, so that the number of input parameters remains at four, as with the other error functions), and the fractions of the total distribution allotted to each family (the fraction belonging to the lower strength family is actually input).

The equations for the distribution are similar to those described in Section A2.3, but with the probability ($p_{x_{s_i}}$) replaced by the probability ($p_{S_{M_i}}$) of each mean strength.

A2.7 Probable Strength, with Discrepancy

a. The distribution of mean strengths, $p_{S_{M_i}}$, which defines the assumed error function, is combined with the basic individual strength distribution, $p_{x_{s_i}}$, to give the probable individual strength distribution in the presence of the error. The synthesis process is identical to that described in section A2.3.b for the incorporation of the fabrication variation. The new distribution, $p_{x_{s_i}}$, replaces the previous distribution, and its cumulative version, $P_{R_{S_i}}$, is formed to replace the previous values of $P_{R_{S_i}}$.

b. The probability distribution of failure, δP_{F_i}, and the cumulative probability of failure, P_{F_i}, are re-estimated, following the procedure of Section A2.5, enabling the reliability to be estimated for the revised state of knowledge (with probable discrepancy, but before testing).

A2.8 Incorporation of Results of First Test

a. The next set of updates can either predict the effects if certain test results are assumed to occur, or can be used to revise the estimates after actual test results have been obtained. Before this step is performed, it is useful to predict the chance that the first test load will be survived. The first test load, x_{T_1}, is defined as the unfactored load, UNFLD, multiplied by the desired test factor, TF_1. Now, the cumulative probability that the strength is less than x_i is defined as $P_{R_{S_i}}$.

Hence, the probability that the strength of the first test specimen will exceed the test load is

$$P_{S_{T_1}} = 1 - P_{R_{S_i}} \qquad \text{A2-40}$$

where i satisfies the condition

$$x_{i_1} - \frac{1}{2}dx < x_{T_1} \leq x_{i_1} + \frac{1}{2}dx \qquad \text{A2-41}$$

where

$$x_{T_1} = UNFLD \cdot TF_1 \qquad \text{A2-42}$$

and $P_{S_{T_1}}$ is then the required probability of surviving the first test.

The probability of a second specimen surviving a test to a load given by

$$x_{T_2} = UNFLD \cdot TF_2 \qquad \text{A2-43}$$

is similarly calculated to be

$$P_{S_{T_2}} = 1 - P_{R_{S_{i_2}}} \qquad \text{A2-44}$$

where

$$x_{i_2} - \frac{1}{2}dx < x_{T_2} < x_{i_2} + \frac{1}{2}dx \qquad \text{A2-45}$$

so that the probability of surviving both tests is

$$P_{T_2} = P_{S_{T_1}} \cdot P_{S_{T_2}} \qquad \text{A-46}$$

and the same process is repeated for the required number of independent tests (of different specimens).

$$P_{T_N} = P_{S_{T_1}} \cdot P_{S_{T_2}} \cdot P_{S_{T_3}} \; \ldots\ldots \; P_{S_{T_N}} \qquad \text{A2-47}$$

b. Three different types of testing can be selected. The first procedure consists of performing N_T tests, each surviving the same load level. The second consists of a series of tests to failure, each of the N_T tests being to a different load, X_{T_N}. The third possibility is a series of N_T survival tests, each test surviving a different load level, X_{T_N}. The implica[illegible]s have been discussed in Section IX, and this Appendix will simply give the equations. Bayes' theorem is used to modify the distribution of mean strengths in a manner which reflects the test results (assumed or actual). Reference 15 contains a useful example of this particular application.

c. N_T tests surviving the same load, X_T:

The prior (before test) distribution of mean strength is already known to be $P_{S_{M_i}}$. The posterior distribution is

$$ {}_{1}P_{S_{M_i}} = \frac{\left(P_{S_{x_T}}\right)_{\bar{x}=x_i} \cdot P_{S_{M_i}}}{\Sigma\left[\left(P_{S_{x_T}}\right)_{\bar{x}=x_i} \cdot P_{S_{M_i}}\right]} \qquad \text{A2.48} $$

where $(P_{S_{x_T}})_{\bar{x}=x_i}$ is the probability of surviving the test load, X_T, when the strength distribution has its mean at $x_i \pm \frac{1}{2}dx$, $P_{S_{M_i}}$ is the probability that the mean is at $x_i \pm \frac{1}{2}dx$, and the denominator is a normalizing factor to ensure that the total posterior probability of all mean strengths remains at unity. The values of $P_{S_{x_T}}$ are calculated from the dispersion properties of the basic strength distribution with the actual values scaled to give a mean at x_i.

If N_T is greater than one, the process is repeated, later, but with the posterior distribution of the previous iteration used as the prior distribution for the subsequent iteration.

It should be noted that the resultant effects of this test procedure are identical to those used in reference 1. Equation A2-48 reduces to the following form if the denominator is assumed to be unity:

$$ {}_{N_T}P_{S_{M_i}} = \left[\left(P_{S_{x_T}}\right)_{\bar{x}=x_i}\right]^{N_T} \cdot P_{S_{M_i}} \qquad \text{A2-49} $$

d. N_T Tests, Each Failing at Load x_{T_i}:

A similar process is employed, but the probability of surviving the test load is replaced by the probability that the strength lies in the interval containing the test load. Hence, the posterior distribution of mean strengths, after the first test, is

$$
{}_1p_{S_{M_i}} = \frac{\left(p_{S_{x_T}}\right)_{\bar{x}=x_i} \cdot p_{S_{M_i}}}{\Sigma\left[\left(p_{S_{x_T}}\right)_{\bar{x}=x_i} \cdot p_{S_{M_i}}\right]} \qquad \text{A2-50}
$$

..d so on. The dependence on the interval width is evident.

e. N_T Tests, Each Surviving Load x_{T_i}

The procedure is similar to the first procedure (paragraph c) but a different x_T is used for each posterior condition.

f. Whichever test process is employed, the revised estimate of the distribution of mean strengths is again used to revise the distribution of individual strengths, enabling a new definition of $p_{S_{x_i}}$. This is used in turn to re-evaluate the failure probabilities and the reliability, following the steps described in A2.5.

A2.9 Incorporation of Subsequent Tests

a. After inclusion of the first test result, a revised estimate can be made of the chance of surviving the second and further tests. The equations are equivalent to those in Section A2.8,a.

b. The means of revising the probable distribution ($p_{S_{M_i}}$) of mean strengths has been described in the previous section. The appropriate posterior distribution leads to an updated distribution ($p_{S_{x_i}}$) of individual strengths, and so to a revised estimate of the failure risk and of the reliability.

APPENDIX III
COMPUTER PROGRAM USED IN STUDY

A3.1 Introduction

The program used in the study was based on the STTREL program of reference 1. The modifications desired made a new program easier to write than their incorporation into the existing program. These modifications comprised:

a) step-by-step computation and print-out of the various stages of the total procedure

b) a constant calculation interval to clarify interpretation

c) the facility for superimposing a fabrication variation on to the basic material strength distribution

d) a wider variety of error functions

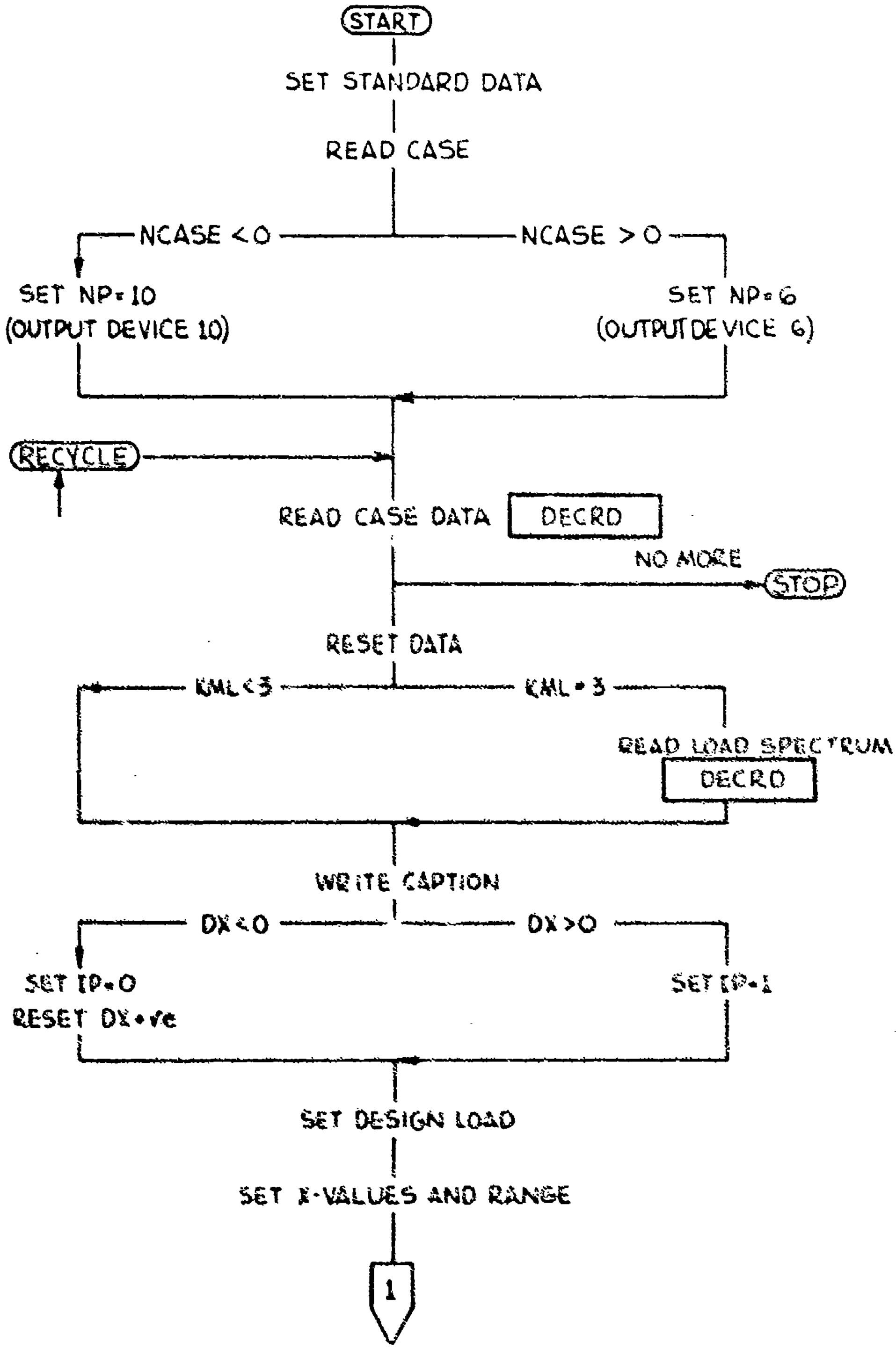
e) the facility for assessing failure tests and survival tests to different test levels

f) the use of double-family Gumbel distributions throughout, except that load spectrum ordinates can be input in place of this distribution.

A3.2 Summary of Program

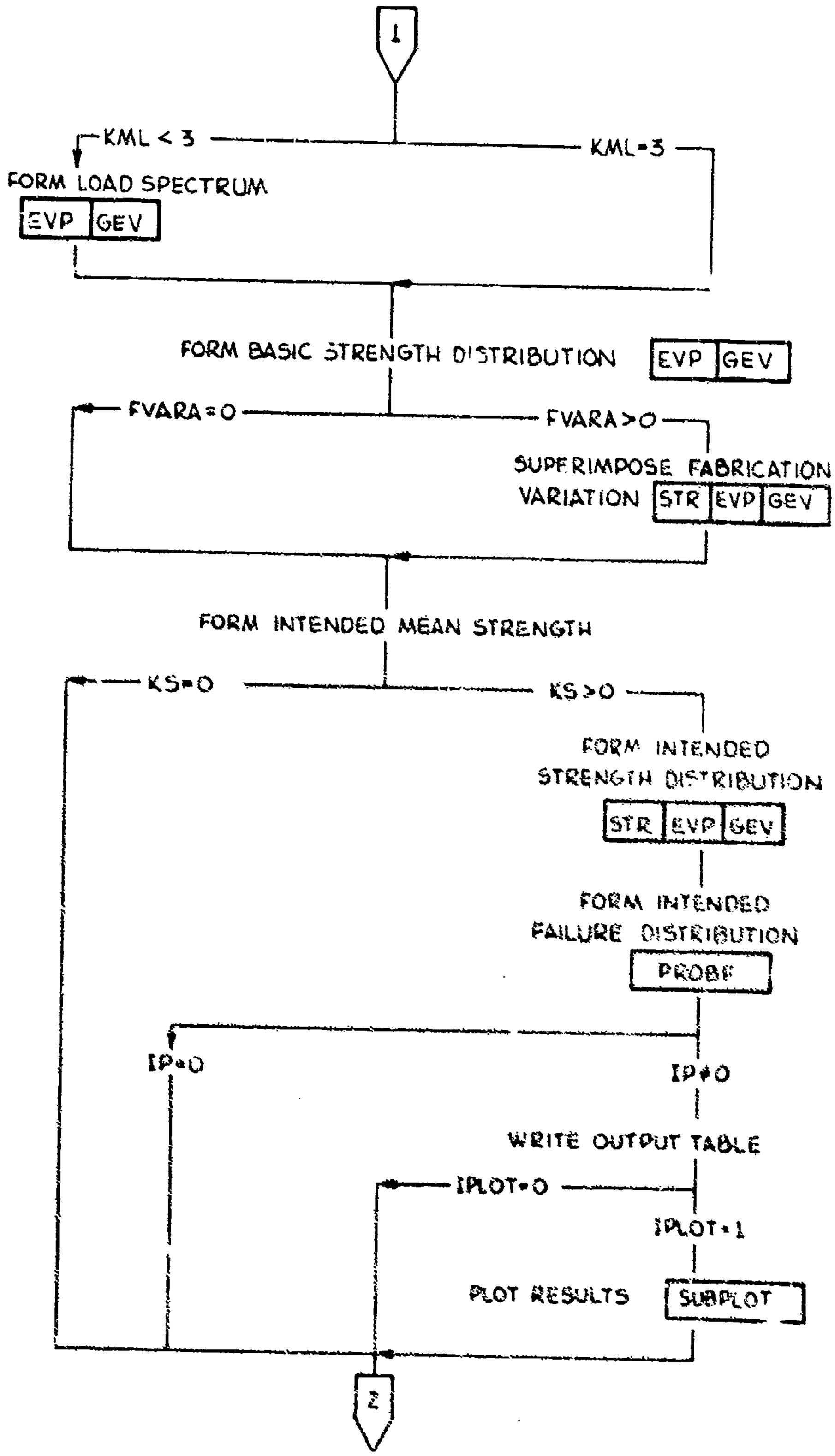
a) The system comprises a main program (STPR), eight subroutines, one function and a data block sub-program. A flow chart of the main program appears in figure 96. A brief description of the main program and of each of the subroutines follows in conjunction with listings of the source decks. The logic employed was as simple as possible, in the interests of clarity and no attempt was made to minimize run times.

The program is written using FORTRAN V for the UNIVAC 1106 Computer with the EXEC-8 operating system. A CALCOMP plot option is available and requires one magnetic tape when used. When the plot option is not used, the only peripherals required are the card reader and printer.



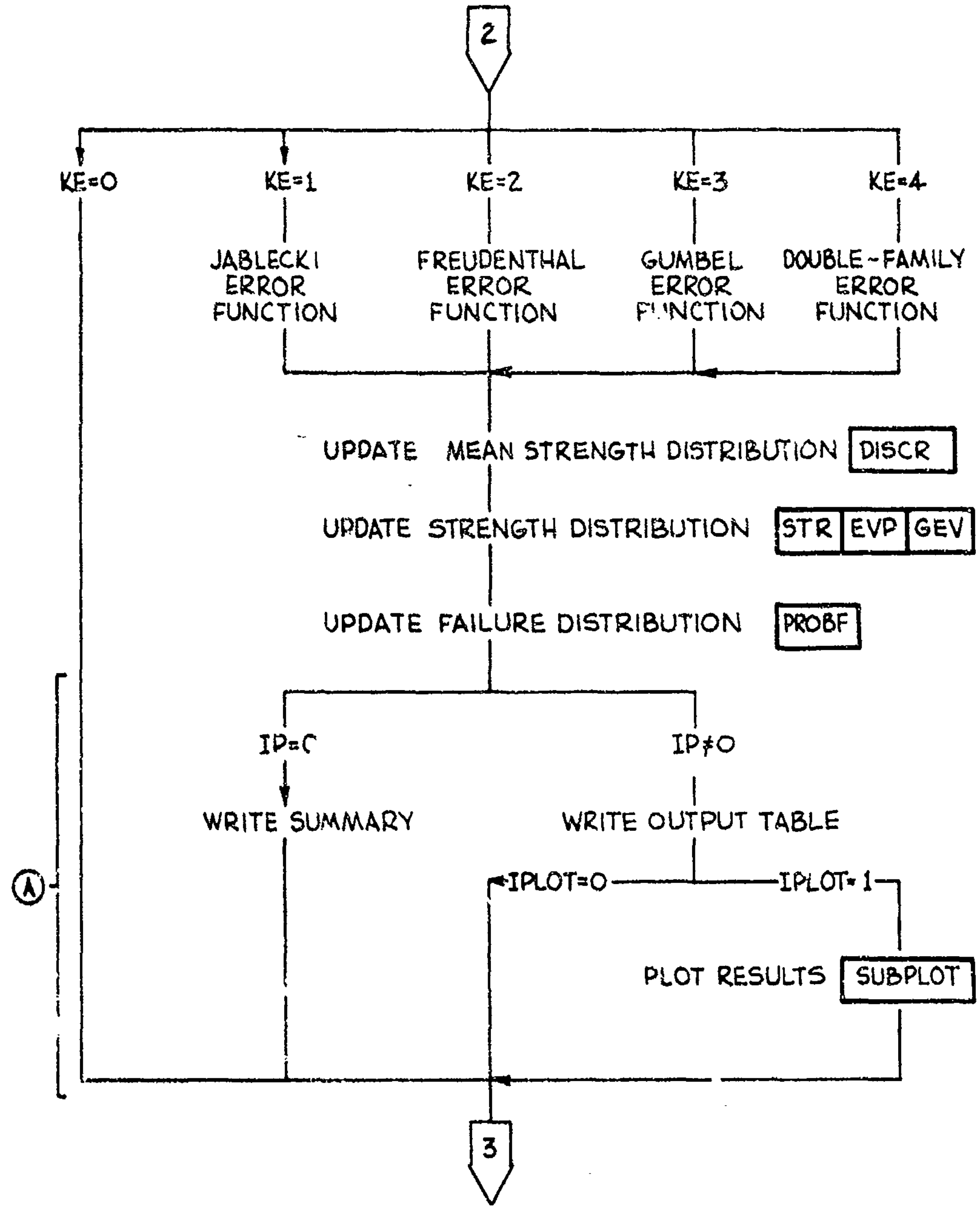
(a) INPUT AND DATA FORMATION STAGE

FIGURE 98. FLOW CHART OF MAIN PROGRAM



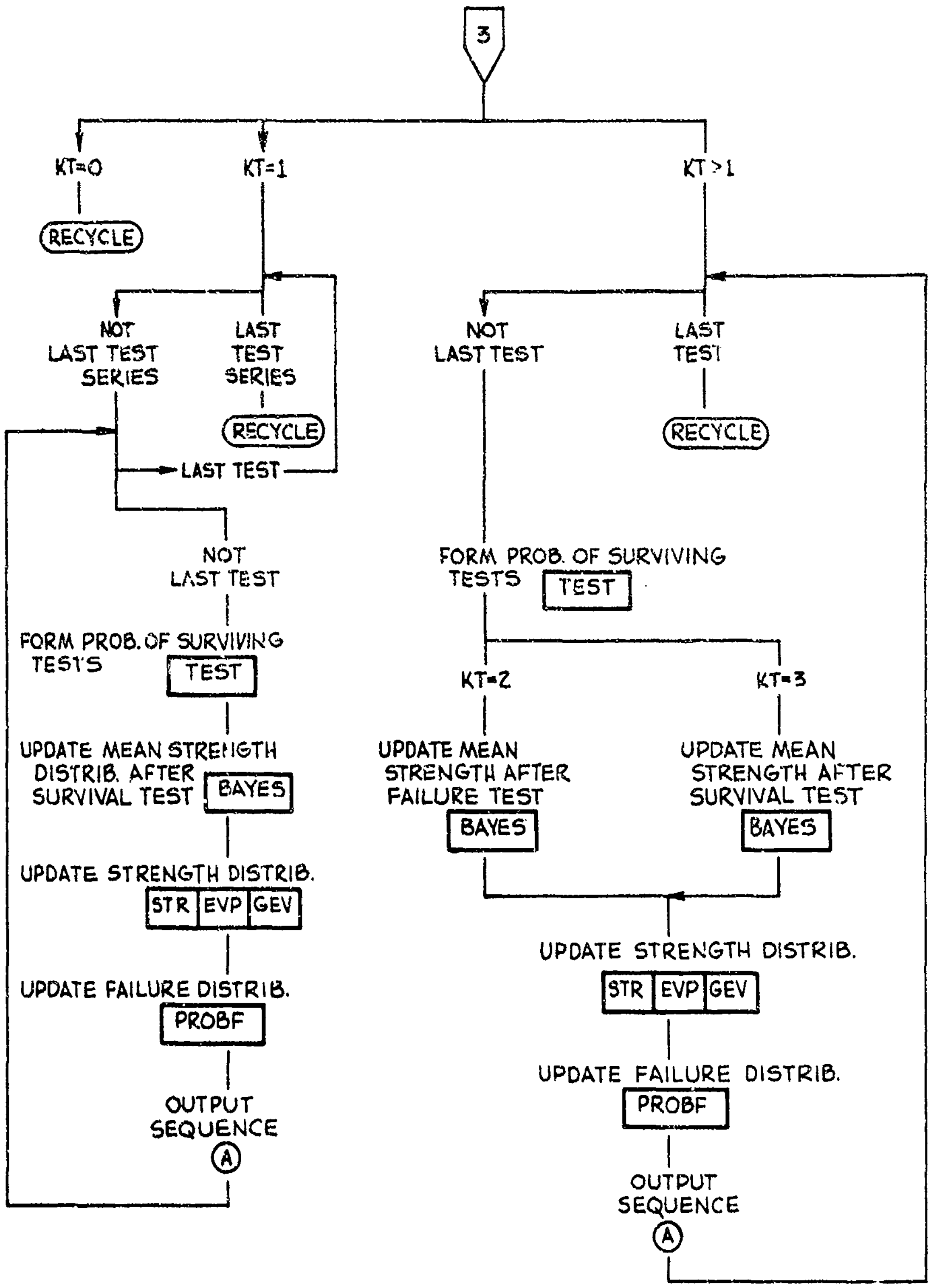
(b) INTENDED STRENGTH STAGE

FIGURE 98. FLOW CHART OF MAIN PROGRAM (CONTINUED)



(c) PROBABLE DISCREPANCY STAGE

FIGURE 98. FLOW CHART OF MAIN PROGRAM (CONTINUED)



(d) TEST RESULT INCORPORATION

FIGURE 98. FLOW CHART OF MAIN PROGRAM (CONCLUDED)

TABLE XXXIV
STPR INPUT LIST

ELEMENT NO.	NAME	STD. VALUE	NOTES
1	UNFLD	100	Design unfactored load (may be either "limit" or "OMEGA")
2	FS	1.5	Design factor of safety applied to UNFLD
3	DX	5.	Calculation interval. If negative, output tables are omitted. (Negative DX must be input for each case)
4	RNB	200.	Permitted No. of intervals. If negative, every line is printed.
5	RKML	1.	Load spectrum option: 1 = input is means and variances of two families 2 = input is intercepts & slopes of families 3 = input is cum. spectrum ordinates (elements 6-10 ignored)
6	LBARA	80.	Load Spectrum: RKML = 1: LBARA, LBARB are means of families of max. loads LVARA, LVARB are variances of families of max. loads LSUMB = fraction in second family (may be negative) RKML = 2: LBARA, LBARB are intercepts of characteristic best st. lines defining the two families LVARA, LVARB are slopes of lines LSUMB - as before
7	LVARA	.05	
8	LSUMB	0.	
9	LBARB	80.	
10	LVARB	.05	
11	SALL	2.326	Factored design load is matched to SALL std. deviations below mean strength.
12	MS	0.	Design margin of safety included in design load.
13	DSNLD	0.	Factored design load if previously defined. Will be updated if present case yields higher value. Re-enter 0 when new case is to define DSNLD.
14	RKS	1.	Print Option: 0 = "no discrepancy" values calculated, but not printed 1 = All blocks printed

TABLE XXXIV (Continued)

ELEMENT NO.	NAME	STD. VALUE	NOTES
15	RKMS	1.	Material strength option: 1 = input is means & variances of two families 2 = input is intercepts & slopes of two families
16	SBARA	150.	MATERIAL STRENGTH SPECTRUM: RKMS = 1: SBARA, SBARB are means of two families; SVARA, SVARB are variances of two families; SSUMB = fraction in second family (may be negative)
17	SVARA	.05	
18	SSUMB	0.	
19	SBARB	150.	RKMS = 2: SBARA, SBARB are intercepts of characteristic best st. lines defining the families; SVARA, SVARB are slopes of lines; SSUMB - as before
20	SVARB	.05	
21	FBARA	100.	FABRICATION SCATTER SPECTRUM: FBARA, FBARB are means of two families; FVARA, FVARB are variances of the families; FSUMB = fraction in second family (may be negative) NOTE: If FVARA is zero, the fabrication scatter is omitted and the material strength definition is used without modification.
22	FVARA	0.	
23	FSUMB	0	
24	FBARB	100.	
25	FVARB	.05	
26	RKE	4.	ERROR FUNCTION CHOICF: 0 = No error considered (see below) 1 = Jablecki function fitted at two pints 2 = Freudenthal function fitted at two points 3 = Gumbel function fitted at two points 4 = Two-family Gumbel distribution
27	PFI	1.	ERROR FUNCTION: RKE = 1, 2 or 3: PFI is cum. prob. of failure when strength less than PPUI x design strength. PF2 is cum. prob. of failure when strength less than PPU2 x design strength. (NOTE - Zero and 1.0 not allowed for any element.) RKE = 4: PFI = mean of main family (achieved str./design str.); PPUI = variance of both families; PF2 = fraction in second family (may be negative); PPU2 = mean of second family
28	PPUI	.05	
29	PF2	0.	
30	PPU2	1.	

TABLE XXXIV (Concluded)

ELEMENT NO.	NAME	STD. VALUE	NOTES
31	RKT	1.	TEST TYPE: 0 = No tests 1 = Tests surviving test load 2 = Test failures at test load } 1 test each 3 = Tests surviving test load
32	RNT	1.	NO. OF TESTS: (MAX. =10 MAY BE ZERO If RKT = 1, RNT tests to each load are considered. If RKT = 2, RNT tests, 1 to each load, are considered. If RKT = 3, RNT tests, 1 to each load, are considered.
33	T(1)	1.5	First test factor, applied to UNFLD
34	T(2)	0.	Subsequent test factors (see notes i.. "RNT")
42	T(10)	0.	
43	XMIN	0.	Elements 43 through 139 are only input if RKML = 3.0: X-value at which first load spectrum ordinate occurs
44	TXI(1)	0.0	Up to 96 load spectrum ordinates, in order of ascending X, starting at XMIN and increasing by DX.
139	TXI(96)	0.0	
140	APLOT	0.0	Plot Option: 0.0 = No plots 1.0 = Plots required

One note regarding output must be made; the program was also operated on the multiple terminal remote-access (DEMAND) system in use at Lockheed-Georgia Company. This system possesses two output modes; WRITE (6, XXX) causes output to be printed on-line; WRITE (10, XXX) enables the output to be internally stored for later offline display. The code NP is set to 6 or 10 according to the sign allotted to the case number. The option may be easily changed to suit the available output device codes.

A3.3 Input Data

This is defined at this point since use of the defined operating controls, etc., simplifies the program descriptions which follow. Table XXXIV defines the various items with their locations in the data block and the standard values built-in.

A3.4 Description of Program

A listing of each of the routines is given, with notes describing the purpose of the appropriate section. The basic equations are given in Appendix II.

If the plot routines are unsuited to the user's computer system, input item 140 should be ignored and the following cards removed:

5 through 35,	65 through 67,	122,	134 through 138,
299 through 309,	317 through 321,	335 through 338,	350 through 354,
373 through 386,	403 through 410,	419 through 422,	427 through 437,
446 through 458,	471 through 477,	482 through 493,	503 through 514,
560,	731 through 738,	740 through 743,	758 through 766,
777 through 787,	802 through 809,	812 through 901,	985 through 992,
994 through 1000,	1017 through 1030,	1045 through 1058.	

a) MAIN PROGRAM

The first 69 lines of the program control the allocation of storage, the definitions of common and data blocks, equivalence statements and other system controls.

```
C      MAIN STPR
       DIMENSION NAME(12),TX(8),PRS2(200)
       COMMON /A/ PXL(200),X(200),NX,PRS(200),PRS(200),PSH(200),PSH2(200)
C****
C         COMMON FOR CALCOMP PLOTS
       COMMON /COMPLT/ XPLTT(402),YPLTT(402),YPLTB(202),XPLTB(202)
      1 ,BUFR,HDGC,F126,F132,F22,HLIN1P,HLIN2P,
      2 HLIN3P,HLIN4P,EBUF(50)
       DIMENSION LBUF(50)
       EQUIVALENCE (EBUF(1),LBUF(1))
       DIMENSION IF 126(3),IF132(13)
C****
C          BUFFERS FOR PLOT TITLES
       DIMENSION BUFR (12),HDGC(19),F126(3),F132(13),
      1 F22(69),HLIN1P(8),HLIN2P(8),HLIN3P(8),HLIN4P(8)
       DIMENSION F111(12),F121(12)
       DATA (F111(I),I=1,12) /'INTENDED STRENGTH     =          BASIC
      1MEAN STRENGTH  =          '/
       DIMENSION          F115(11),F120(11),F131(11),F135(11)
       EQUIVALENCE (HDGC(4),NAME(1))
       DATA (F115(I),I=1,11)/'INTENDED FAILURE PROB., NO DISCREPANCY, NO
      1TEST              '/
       DATA (F120(I),I=1,11)/'PREDICTED FAILURE PROB. WITH PROB. DISCREPA
      1NCY, NO TEST          '/
       DATA (F121(I),I=1,12) /'REVISED MEAN STRENGTH =
      1           VAR =            '/
       DATA (F131(I),I=1,11) /'UPDATED FAILURE PROB. AFTER          TESTS
      1 TO PASS SAME LOAD        '/
       DIMENSION (F131(11),IF135(11))
       EQUIVALENCE (F126(1),IF126(1))
       EQUIVALENCE (F132(1),IF132(1))
       DATA (F135(I),I=1,11) /'UPDATED FAILURE PROB. AFTER          TESTS
      1 TO ACTUAL FAILING LOAD '/
       EQUIVALENCE (F131(1),IF131(1)), (F135(1),IF135(1))
C****
C
C                  *** VARIABLE INPUT DATA ***
C              DATA TO BE CHANGED FROM THE BASIC VALUES LISTED
C              BELOW ARE ENTERED IN THE LOCATIONS INDICATED
C              IN DECIMAL FORM.
C
C         LOADS
C                         (1)     (2)     (3)     (4)     (5)
       COMMON /DATA/  URLLD,   P3  ,   Q4  ,  [illegible] ,  [illegible],
C
C                         (6)     (7)     (8)     (9)     (10)
      1                 LBARA,  LVARA,  LSUMB,  LVARB,  [illegible],
C          INTENDED STRENGTH
C                         (11)    (12)    (13)    (14)    (15)
      2                 SALL ,   MS  , DSALD ,  [illegible] ,  [illegible] ,
C
C                         (16)    (17)    (18)    (19)    (20)
      3                 SBARA,  SVARA,  SSUMB,  SVARB,  [illegible],
C
C                         (21)    (22)    (23)    (24)    (25)
      4                [illegible] , FVARA , FSUMB , [illegible] , FVARB ,
C          ERROR FUNCTION
C                         (26)    (27)    (28)    (29)    (30)
      5                 [illegible] ,  PF1  , PF01 ,  PF3  , PFV2 ,
C          TEST RESULTS
C                         (31)    (32)    (33)
      5                 NXT  ,  NWT  ,  TT(8)
C              (34)    (35)
      6      [illegible] , TAIL[illegible]
C         PLOT OPTION
C          (36)
      7 , APLOT
C
       REAL LBARA,LVARA,LSUMB,LBARB,LVARB,MS,[illegible]
```

a) MAIN PROGRAM (Continued)

Lines 70 through 115 initialize the data. The standard values are those of Table A3-I.

Lines 116 through 132 read the case number for the first case of the run and set the output device code, NP. The "99 Continue" statement is the return point for recycling and is followed by the read statement for the case caption and the addition of 1 to the previous case number.

Line 133 calls DECRD to input the case data, which is confined to any changes from the previous case. When the first case data is input, it consists of changes to the standard data (but must contain one entry).

Lines 134 through 138 set buffers for the plot routines. Lines 139 through 142 set the output format control, IP, according to the sign of the interval, DX. If DX is negative IP = 0 and only the summary items are output, the tables being omitted. If DX is positive, IP = 1 and the tables are included in the output (see also line 207).

When not using FORTRAN V, card 133 may be changed to

CALL DECRD (UNFLD)

and cards 518 and 552 in DECRD should then be changed as described in para. (b).

```
C        THE FOLLOWING ARE PRESET BUT OVERRIDDEN BY CASE INPUT
C *      LOADS
      UNFLD=100.
      FS=1.5
      DX=5.0
      RNB=100.
      RKNL=1.
      LBARA=80.
      LVARA=.05
      LSUMB=0.
      LBARB=80.
      LVARB=.05
C        INTENDED STRENGTH
      SALL=2.326
      HS=0.
      DSLLO=0.
      RKS=1.
      RKNS=1.
      SBARA=150.
      SVARA=.05
      SSUMB=0.
      SBARB=150.
      SVARB=.05
      FBARA=100.
      FVARA=0.
      FSUMB=0.
      FBARB=100.
      FVARB=.05
C        ERROR FUNCTION
      RKE=4.
      PF1=1.
      PPV1=.05
      PF2=0.
      PPV2=1.
C        TEST RESULTS
      RKT=1.
      RNT=1.
      T(1)=1.5
      XMIN=0.0
      DO 78 I=2,10
   78 T(I)=0.
      DO 77 I=1,200
      PXS(I)=0.
      PRS(I)=0.
   77 PAL(I)=0.
      IPLOT=0
C****
C        INITIAL CASE NUMBER
      READ(5,100) CASE
  100 FORMAT (I5)
      IF(NCASE) 95,1,9A
    1 CONTINUE
      IF (IPLOT .NE. 0) CALL PLOT (0.0,0.0,999)
      STOP
   95 NP=10
      NCASE=-NCASE
      GO TO 2
   9A NP=4
    2 NCASE=NCASE-1
   99 CONTINUE
      READ(5,101) NAME
  101 FORMAT(12A6)
      NCASE=NCASE+1
      CALL MYCRO (UNFLD,41)
      IPLOT=IPLOT
      IF (IPLOT .EQ. 0) GO TO 3000
      ENCODE (LAUF,AGOU) NCASE
      NAGC(3)=EQUF(1)
 3000 CONTINUE
      I=1
      IF(UA) 97,97,94
   97 I=0
      DA=ABS(DX)
```

a) MAIN PROGRAM (Continued)

Lines 144 through 169 only apply if the load spectrum ordinates are input. The input values, TXI, are transferred into the load spectrum array PXL until a value less than 0.1 E-19 is encountered; the rest of the PXL array is zeroed. Values greater than unity are set to unity (a probability of unity represents certainty and greater values have no meaning).

Lines 170-171 ensure that all values of X below XMIN are associated with a load spectrum probability of unity, so that XMIN can be set at the highest X-value with this probability, and the input data reduced in volume.

The case number and caption are written (lines 172 through 180), followed by a print-out of the data (as set for the case), provided that IP is not zero.

Lines 200 through 205 form the factored design load for the case, and if this is less than the maximum value previously encountered in the run, retains the previous value.

```
   98 IF(BKOL-2.5) 76,78,79
   79 CONTINUE
      IF(ABS(SKIN)-.01) 80,80,81
   80 WRITE(6,107)
  107 FORMAT(5X,'XMIN MUST NOT BE ZERO')
      STOP
   81 I=(AMIN-DA)/DX+.01
      L=0
      IA=1
      ITX=0
   73 CONTINUE
      DO 730 J=1,6
      IT=IT+1
  730 TA(J)=TS(ITA)
      DO 74 J=1,6
      IF (TA(J)-1.0) 84,84,85
   85 TA(J)=1.0
      GO TO 76
   84 IF(TA(J)-1.E-19) 86,76,76
   76 I=I+1
      L=L+1
   74 PA(L)=P*TA(J)
      GO TO 73
   86 IF (L-2) 71,88,88
   88 L=L-1
      GO TO 87 (?) I=L,200
   87 PA(I)=0.
   71 DO 82 J=1,IA
   82 PA(J)=0.0
   78 IF(NPR-2) 13,13,12
   13 [illegible]
   91 WRITE(6,105) NCASE,NAME
      GO TO 11
   90 WRITE(6,107) NCASE,NAME
  102 FORMAT([illegible])
      GO TO 11
   12 WRITE(12) NCASE,NAME
  105 FORMAT(//25X,'CASE ',I3/[illegible])
   11 IF([illegible]) 40,[illegible]
   20 WRITE(6,103) [illegible]
      [illegible]
      [illegible]
  103 FORMAT([illegible])
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
C     SET BASIC AND LOAD PROD. PARAMETERS
   21 [illegible]
      [illegible]
      [illegible]
      IF(PUPPLD-[illegible]) 3,4,4
    4 [illegible]
      [illegible]
```

a) MAIN PROGRAM (Continued)

Line 206 sets the maximum number of intervals allowed for the case (if different from the standard value). If the input value, RNB, is negative, the output control is reset at line 207 to IP = -1 and represents a command to print every line. If RNB is positive, IP = +1 and the output table is truncated as described in PROBF.

Lines 208 through 232 form the number of calculation intervals. A range from XMIN to twice DSNLD is assumed, with a band edge coinciding with UNFLD. The resulting number of bands is compared with the permitted number, NB, and if too large, is curtailed at the upper end. The highest value of X is compared with the highest test load to be used and the assumed range increased if necessary, up to the limit implied by NB.

Lines 233 through 239 initialize the mean strength arrays, PSM and PSM2, and set the X values, ensuring that a zero value for X is not used.

If KML is 1 or 2, the load spectrum is formed from the input properties of a double-family description of the probability that X is the maximum load encountered. Appendix II describes this process, which covers lines 242 through 273.

```
    3 NP=IABS(NUB*SIGN(1.,NUB))
      IP=ISIGN(IP,NPB)
      ALIM=USLD*2.
      N2=IA(IM-UNFLD)/DA+.01
      N1=INT(UNFLD/DA)
      A1=UNFLD-DA*(N1)
      SS=1
      NAN=N1+2
      IF(NA-N1) 5,5,72
   72 NA=N1+1
      NAN=N1+2
      ALIM=UNFLD+2*DA
    5 TMAX=T(1)
      DO 150 J=2,IL
      IF(T(J)-TMAX) 150,150,151
  151 TMAX=T(J)
  150 CONTINUE
      TALO=TMAX*UNFLD
      IF(TALO-DA*L(M)) 155,155,152
  152 N2=(1.2*TALO-UNFL)/DA+.01
      NAN=N1+2
      IF(NA-N2) 153,153,154
  154 WRITE(6,123)
  123 FORMAT(1X,'ANALYSIS INADEQUATE. CASE ENDED')
      GO TO 99
  153 WRITE(6,124)
  124 FORMAT(1X,'INTERVAL INCREASED TO COVER TEST LOADS')
  155 DO 7 I=1,NA
      P3(I)=0.0
      P4(I)=0.0
    7 [illegible]
      [illegible]
  156 [illegible]
  157 CONTINUE
      [illegible]
      IF([illegible]) [illegible]
    4 [illegible]
      [illegible]
      GO TO [illegible]
    9 [illegible]
      [illegible]
   10 [illegible]
      CALL [illegible]
    8 WRITE(6,110) [illegible]
  110 FORMAT([illegible]'LOAD [illegible]
     1[illegible]
      J=0
      DO 37 I=2,NA
      IF([illegible]) 36,36,[illegible]
   36 J=I
   37 CONTINUE
      WRITE(6,125)
  125 FORMAT(1X,'LOADS SPECTRUM [illegible]. CASE ENDED')
      GO TO 99
   35 [illegible]
   39 [illegible]
      J=J-1
      DO 99 I=1,J
   99 [illegible]
   30 [illegible]
   14 WRITE(6,122) [illegible]
  122 FORMAT(1X,'USE [illegible]' FROM PREVIOUS CRITICAL CASE')
   17 IF([illegible]) 18,18,19
   18 WRITE(6,132) [illegible]
  132 FORMAT(1X,'MEAN MAX. LOAD [illegible]', [illegible])
      GO TO 19
   16 WRITE(6,113) [illegible]
  113 FORMAT(1X,'LOADS SPECTRUM INPUT FROM MAIN [illegible])
```

a) MAIN PROGRAM (Continued)

The statements of lines 276-285 represent the formation of the basic strength distribution as defined by elements 15-20 of the input data. If the fabrication variation is to be superimposed (FVARA not "zero"), then STR is used for this purpose as in lines 286-292. The basic strength distribution, PXS, is copied into PSM and PSM2 which are then modified within STR. The coefficient of variation of the resulting distribution, VARS, is used in line 293 to define the intended mean strength by matching the design load to a strength which is SALL standard deviations below the mean. The intended strength distribution properties are then printed at lines 295-298.

Data is set for the plot routine in lines 299-309. If the "no error" probabilities of failure are to be printed (KS = 1), the heading is written at lines 315-316. The intended distribution of mean strengths, with no error, contains unity for the band containing the intended mean, but is zero elsewhere, as given by lines 322-331.

The intended strength distribution is formed by STR, followed by the use of PROBF to form and write the failure probabilities and reliability. If IPLOT = 1, the values are then plotted at line 338.

```
C****
C        IF KS=1, FORM AND PRINT INTENDED PROB. OF FAILURE
   16 KMS=KMS+1
      IF(KMS-1) 22,22,23
   22 SSTA=SVARA*SHARA
      SSTB=SVARB*SBARB
      GO TO 24
   23 SSTA=SVARA
      SSTB=SVARB
   24 K=-1
      CALL EVP(K,KMS,SHARA,SSTA,SSUMB,SHARB,SSTB,BARSD,VARSD)
      VARS=VARSD
      IF(FVARA-.001) 25,25,26
   26 DO 27 I=1,NX
      PSH(I)=PXS(I)
   27 PSH2(I)=PAS(I)
      FBAR=FBARA*(1.-FSUMB)+FBARB*FSUMB
      CALL STR(KMS,FBARA,FVARA,FSUMB,FBARB,FVARB,FBAR,
     10.0,0.0,0.0,BARS,VARS)
   25 AMSTR=DSNLD/(1.0-SALL*VARS)
      STS=AMSTR*VARS
      WRITE(NP,111) AMSTR,STS,VARS,BARSD,VARSD
  111 FORMAT(5X,'INTENDED STRENGTH',5X,'AMSTR =',F10.3,', STS =',F10.3,
     1', VARS =',F6.3/10X,'BASIC (MATERIAL) MEAN STRENGTH =',F10.3,
     2', VAR =',F6.3)
      IF(IPLOT .EQ. 0) GO TO 4000
      DO 5000 I=1,12
      BUFR(I)=F111(I)
 5000 CONTINUE
      ENCODE (EBUF,6050)AMSTR
      BUFR(5)=EBUF(1)
      BUFR(6)=EBUF(2)
      ENCODE (EBUF,6050) BARSD
      BUFR(11)=EBUF(1)
      BUFR(12)=EBUF(2)
 4000 CONTINUE
      IF(FVARA-.001) 28,28,29
   29 WRITE(NP,116) BARS,VARS
  116 FORMAT(5X,'RESULTANT BASIC MEAN STRENGTH =',F10.3,', VAR =',F6.3)
   28 KS=KS+1
      IF(KS-1) 30,31,31
   31 WRITE(NP,115)
  115 FORMAT(/5X,'INTENDED FAILURE PROB., NO DISCREPANCY, NO TEST')
      IF (IPLOT .EQ. 0) GO TO 4001
      DO 5001 I=1,11
      IH=I+0
 5001 HUGC(IH)=F115(I)
 4001 CONTINUE
      JH=NX
      DO 32 I=1,NX
      PSH(I)=0.
      PSH2(I)=0.
      IF(X(I)+.5*DX-AMSTR) 32,33,33
   33 IF(X(I)-.5*DX-AMSTR) 34,32,32
   34 JH=I
   32 CONTINUE
      PSH(JH)=1.0
      PSH2(JH)=1.0
      CALL STR(KMS,SHARA,SVARA,SSUMB,SHARB,SVARB,BARSD,
     1FBARA,FVARA,FSUMB,FBARB,FVARB,BART,VARS)
      CALL PROOF(NST,NI,NP,IP)
      IF (IPLOT .EQ. 0) GO TO 30
      NPLTS=NX
      IF (IP .GE. 0) NPLTS=NX-NST+1
      CALL SUBPLT (0,NPLTS)
```

a) MAIN PROGRAM (Continued)

Line 339 forms the error function option, KE. The heading is written (line 347) and stored for plotting. At lines 355-356, the input data PFI and PPU2 are temporarily held in dummy storage so that their meaning can be changed for the double-family error function (KE = 4).

DISCR is called at line 361; this modifies the distribution of probable mean strength, PSM, by one of the four error function routines. If the fourth is used, PFI and PPU2 are reset at lines 362-363. STR is called at line 368 to use the revised PSM array for the formation of a new PXS array, which is then employed in the re-evaluation of the failure probabilities and reliability, using PROBF (line 372). If IPLOT = 1, the necessary data is transferred to the plot routine buffers, at lines 374-386.

Line 387 sets the test option, KT, and line 394 sets the number of tests, NT. When KT = 1, this implies NT tests to each non-zero test factor; when KT = 2 or 3, this implies NT tests, one to each of the NT test factors input.

Lines 395-396 duplicate the cumulative probability of a given strength in PRS2, to enable the original values to be retained in PRS for later use.

```
   30 KE=KKE+1
C        IF KE=0, IGNORE PROBLE ERRORS
C        IF KE=1, PREDICT ERRORS USING JABLECKI FUNCTION
C        IF KE=2, PREDICT ERRORS USING FREUDENTHAL FUNCTION
C        IF KE=3, PREDICT ERRORS USING GUMBEL FUNCTION
C     IF KE=4, USE GUMBEL FUNCTION (SINGLE OR DOUBLE) WITH SPECIFIED
C                 MEANS AND VARIANCE
      IF(KE) 50,50,41
   41 WRITE(NP,120)
  120 FORMAT(/5X,'PREDICTED FAILURE PROB., WITH PROBABLE DISCREPANCY,',
     1' NO TEST')
      IF (IPLOT .EQ. 0) GO TO 4002
      DO 5002 I=1,11
      IH=I+6
 5002 HDGC(IH)=F120(I)
 4002 CONTINUE
      DUM1=PF1
      DUM2=PPU2
      KSTOP=0
      IF(KE-3) 40,40,46
   46 PF1=PF1*DSHLD
      PPU2=PPU2*DSHLD
   40 CALL DISCR(KE,KSTOP,NP)
      PF1=DUM1
      PPU2=DUM2
      IF(KSTOP) 42,42,99
   42 DO 43 I=1,NX
   43 PSH2(I)=PSH(I)
      KMS=KKMS+1
      CALL STR(KMS,SBARA,SVARA,SSUMB,SBARB,SVARB,BARSD,
     1FBARA,FVARA,FSUMB,FBARB,FVARB,BART,VARS)
      WRITE(NP,121) BART,VARS
  121 FORMAT(10X,'REVISED MEAN STRENGTH =',F10.3,', VAR =',F6.3)
      CALL PROBF(NST,NI,NP,IP)
      IF (IPLOT .EQ. 0) GO TO 4003
      DO 5004 I=1,12
 5004 BUFR(I)=F121(I)
      ENCODE (EBUF,6050) BART
      BUFR(5)=EBUF(1)
      BUFR(6)=EBUF(2)
      ENCODE (EBUF,6051) VARS
      BUFR(11)=EBUF(1)
 6050 FORMAT (F10.3)
 6051 FORMAT (F6.3)
      NPLTS=NX
      IF (IP .GE. 0) NPLTS=NX-NST+1
      CALL SUBPLT (0,NPLTS)
 4003 CONTINUE
   50 KT=KKT+1
C        IF KT=0, NO TEST
C        IF KT=1, FORM FAILURE PROB. AFTER PASSING N TESTS TO SAME
C        TEST LOAD
C        IF KT=2, FORM FAILURE PROB. AFTER N FAILURE TESTS
C        IF KT=3, FORM FAILURE PROB. AFTER N SURVIVAL TESTS
      IF(KT) 99,99,51
   51 NT=KNT+1
      DO 66 I=1,NX
   66 PRS2(I)=PRS(I)
      KSTOP=0
      GO TO (52,60,70),KT
```

a) MAIN PROGRAM (Continued)

The operations on this page incorporate the effects of NT tests surviving each of the input test load levels, defined by a test factor applied to the unfactored load.

The headings are formed (and stored for the plot routine) in lines 400 through 410. The counter, MT, is initialized as 1 and the first test factor tested for a "non-zero" value. Headings are written (and stored) in lines 417 through 437, and TEST is called to form the probability of surviving all subsequent tests. BAYES is then used to update the mean strength distribution, PSM2, this then being used to update the individual strength distribution, PXS, by means of STR. PROBF is used to form the failure distribution and reliability and the values are stored in the plot routine buffers (lines 445 through 457).

This process is repeated for the remaining tests to the first test level (the loop from line 423 to line 459). MT is increased to 2 and the whole process repeated by a return to line 412. When a "zero" test factor is encountered, the case is ended by returning to line 129.

```
C          BAYES PROCEDURE FOR TEST SURVIVAL
      52 WRITE(NP,131) NT
     131 FORMAT(/5X,'UPDATED FAILURE PROB. AFTER',5X,I3,' TEST(S) TO ',
        1'PASS TEST LOAD')
         IF (IPLOT .EQ. 0) GO TO 4004
         ENCODE (LBUF,6000) NT
    6000 FORMAT (I2)
         IF131(6)=LBUF(1)
         DO 5003 I=1,11
         IH=I+8
    5003 HUGC(IH)=F131(I)
    4004 CONTINUE
         NT=1
      53 IF(T(NT)-.01) 99,54,54
      54 DO 57 I=1,N4
         PRS(I)=PRS2(I)
      57 PSP2(I)=PSN(I)
         AT=UNFLD*T(NT)
         WRITE(NP,126) NT
     126 FORMAT(/5X,'TEST SERIES ',I2)
         IF (IPLOT .EQ. 0) GO TO 4005
         ENCODE (LBUF,6000) NT
         IF126(3)=LBUF(1)
    4005 CONTINUE
         DO 55 J=1,NT
         WRITE(NP,132) J,T(NT),AT
     132 FORMAT(5X,'TEST NO. ',I2,', TEST FACTOR =',F5.3,', TEST',
        1' LOAD =',F10.3)
         IF(IPLOT .EQ. 0) GO TO 4015
         ENCODE (LBUF,6000) J
         IF132(1)=LBUF(1)
         ENCODE (EBUF,6011) T(NT)
         F132(6)=EBUF(1)
         F132(7)=EBUF(2)
         ENCODE (EBUF,6150) AT
         F132(10)=EBUF(1)
         F132(11)=EBUF(2)
         F132(12)=EBUF(3)
    4015 CONTINUE
         CALL TEST(KT,AT,NP,J,NT,N4,KSTOP,UNFLD,T,PRS,NR,4,IPLOT)
         IF(KSTOP) 65,65,99
      66 CALL CAYES(KT,AT,KSTOP,NP)
         IF(KSTOP-1) 63,99,55
      63 CALL STRIKNS,SHARA,SVARA,SSUMR,SHARB,SVARB,BANSD,
        1FHARA,FVARA,SUMB,FHARB,FVARB,BANT,VANS)
         WRITE(NP,1  ) BANT,VANS
         CALL LROHE(NSF,N1,NP,IP)
         IF (IPLOT .EQ. 1) GO TO 4007
         DO 5010 I=1,12
    5010 BUFR(I)=F121(I)
         ENCODE (EBUF,6050) BANT
         BUFR(5)=EBUF(1)
         BUFR(6)=EBUF(2)
         ENCODE (EBUF,6051) VANS
         BUFR(11)=EBUF(1)
         NPLTNT=J+1
         NPLTS=N4
         IF (IP .GE. 2) NPLTS=(N-5)+1
         CALL SLOPE1 (NPLT,NPLTS)
    4007 CONTINUE
      55 CONTINUE
         NT=NT+1
         GO TO 53
```

a) MAIN PROGRAM (Concluded)

The final operations are similar to those on the previous page, but are for the remaining two test options. In both cases, NT tests are made, one to each of the NT test factors. When KT = 2, the tests result in failure at a load assumed to lie in the band containing the value; for KT = 3, the test survives the specified load.

The appropriate heading is written by line 463 or 468 and is stored for plotting in lines 471 through 477. The pre-test distribution of mean strength is copied into PSM2 which is then updated by BAYES (line 497), and used to update the individual strength distribution (STR is called at line 499); these new values of PXS are then used in PROBF to re-evaluate the failure distribution and reliability, which are stored in the plot buffers (lines 503 through 514).

This loop (lines 480 through 515) is repeated for each of the tests, after which the program returns control to line 129 for the next case.

```
C          BAYES PROCEDURE FOLLOWING ACTUAL TEST RESULTS
   60 WRITE(NP,135) NT
  135 FORMAT(/5X,'UPDATED FAILURE PROB. AFTER',5X,I2,' TEST(S) TO ',
     1'ACTUAL FAILING LOAD')
      LT=2
      GO TO 75
   70 WRITE (NP,131) NT
      LT=1
   75 CONTINUE
      IF (IPLOT .EQ. 0) GO TO 4008
      ENCODE (LBUF,4000) NT
      IF135(6)=LBUF(1)
      DO 5008 I=1,11
      IH=I+6
 5008 HDG(IH)=F135(I)
 4008 CONTINUE
      DO 61 I=1,NX
   61 PSH2(I)=PSH(I)
      DO 62 J=1,NT
      XI=UNFLD*T(J)
      IF (IPLOT .EQ. 0) GO TO 4009
      ENCODE (LBUF,4000) J
      IF132(3)=LBUF(1)
      ENCODE (EBUF,4011) TIMI)
      F132(6)=EBUF(1)
      F132(7)=EBUF(2)
 4011 FORMAT (F5.3)
      ENCODE (EBUF,4050) XT
      F132(10)=EBUF(1)
      F132(11)=EBUF(2)
      F132(12)=EBUF(3)
 4009 CONTINUE
      WRITE(NP,132) J,T(J),XT
      CALL TESTIXT,AT,NP,J,XT,DA,KSTOP,UNFLD,T,PHS,NA,,IPLOT)
      IF(KSTOP) 67,67,99
   67 CALL LATEST(T,AT,KSTOP,NP)
      IF(KSTOP) 64,64,99
   64 CALL STRIKHS,SNARA,SVARA,SSUMD,SDAHM,SYAND,NANSD,
     1FNARA,FVARA,FSUMD,FDAHM,FYAND,NANT,VANS)
      WRITE(NP,121) NANT,VANS
      CALL PRODF(NST,XI,NP,IP)
      IF (IPLOT .EQ. 0) GO TO 62
      DO 5014 I=1,14
 5014 BUF(I)=F121(I)
      ENCODE (EBUF,4050) NANT
      BUF(5)=EBUF(1)
      BUF(6)=EBUF(2)
      ENCODE (EBUF,4051) VANS
      BUF(11)=EBUF(1)
      NPLT=NT-1+J*3
      NPLTS=NAA
      IF (IP .GE. 0) NPLTS=NA*NST+1
      CALL SUBPLT (NPLT,NPLTS)
   62 CONTINUE
      GO TO 99
      END
```

b) DECRD

This decimal read routine is similar* in effect to the one used (but not listed) in reference 1. The description in reference 1 remains applicable and is reproduced here.

In the Decimal Read data input method, each card is divided into six fields, each containing 12 columns. The first field is reserved for the index which is the Data array location of the data in the second field on the card, so that five fields are available for data. However, it is not necessary to supply a number in each field; if a field is blank, the program will retain the variable unchanged from the value already stored in the DATA array. The remaining four fields on each card represent the location of variables which are in numerical sequence after the first location.

c) EVP

This routine forms the distribution properties of the load or strength, using Gumbel equations for double-families. For the load spectrum, maximum extremes (K = +1) are used, the tail extending towards higher loads; for the strength spectrum, minimum extremes (K = -1) are used, the tail extending towards lower strengths.

Lines 1 through 10 allot storage, etc., and are followed by definition of the intercepts and slopes of the characteristic straight lines of the Gumbel plots. The overall mean of the double family is formed at line 30, and the summation terms are initialized in lines 31-34.

---

*When not using FORTRAN V, cards 518 and 552 should be changed to

```
      SUBROUTINE DECRD (RKI)
550   STOP
```

```
      SUBROUTINE DECRD (RK1,*)
      DIMENSION RK1(2)
      DIMENSION A(5)
C****
C         ROUTINE TO READ A CARD CONTAINING 6 FIELDS 12 COLUMNS WIDE.
C         THE FIRST FIELD CONTAINS THE INDEX IN THE ARRAY RK1 TO STORE
C         THE VALUE IN THE 2ND FIELD. THE 3RD THROUGH 6TH FIELDS GO
C         INTO  INDEX+1,+2,ETC. BLANK FIELDS ARE NOT STORED IN RK1.
      ASSIGN 10 TO NEXT
   10 READ (5,1000,ERR= 550,END= 550) INDEX,(A(I),I=1,5)
 1000 FORMAT (I12,5G12.5)
      IF (INDEX) 100,90,105
   90 CONTINUE
C****
C         INDEX IS ZERO, USE LAST INDEX+1
      INDEX=INDSAV+1
      GO TO 105
  100 CONTINUE
C****
C         THIS IS THE LAST DATA CARD.
      ASSIGN 500 TO NEXT
      INDEX=-INDEX
  105 CONTINUE
      INDSAV=INDEX
C****
C         IF FIELD IS BLANK, DONT STORE IT IN RK1.  RETAIN PREVIOUS VALUE
      DO 110 I=1,5
      IF (A(I) .EQ. 0.0) GO TO 110
      INX=INDEX+I-1
      RK1(INX)=A(I)
  110 CONTINUE
      GO TO NEXT (10,500)
  500 CONTINUE
      RETURN
  550 RETURN 2
      END
```



```
      SUBROUTINE EXP1(A,NM,BARA,STA,SUMA,BARB,STB,BART,VAR)
      COMMON /A/ PAL(200),X(200),[illegible],PAS(200),PHS(200),PSH(200),PSH2(200)
      COMMON /DATA/ [illegible],PS,DA,RHO,RKHL,LBARA,LVARA,LSUMA,LBARB,LVARB,
     1SALL,DS,DSALC,RKS,RKHS,SHARA,SVARA,SSUMB,SHARB,SVARB,FBARA,FVARA,
     2FSUMA,FBARB,FVARB,RAC,PF1,PPU1,PF2,PPU2,RKT,RNT,T(10)
     6 ,[illegible] TAI(V8)
     7 ,IPLOT
      REAL LVARA,LVARA,LSUMA,LBARB,LVARB,MS
      DOUBLE PRECISION FA,FB,FT,SLV,ONE,FAA,FBB,FTT,GE,PST,PAT
      ONE=1.0
      BETAA=STA
      BETAB=STB
      IF(A)1,1,2
    1 BARA=BARA*K
      BVARB=BARB*K
      BETAA=BETAA/1.28255
      BETAB=BETAB/1.28255
      ALPHA=BARA-0.57722*BETAA
      ALPHB=BARB-0.57722*BETAB
      GO TO 3
    2 STA=1.28255*BETAA
      STB=1.28255*BETAB
      ALPHA=BARA*K
      ALPHB=BARB*K
      BARA=ALPHA+0.57722*BETAA
      BARB=ALPHB+0.57722*BETAB
      BARA=BARA*K
      BARB=BARB*K
    3 SUMA=[illegible]=SUMB
      [illegible]
    4 SUM=0.
      SUMA=0.
      SUMA2=0.
```

c) EVP (Concluded)

The basic loop comprises lines 35 through 85. For each band of the variable, X, the cumulative probabilities are formed at the band edges for both of the families. The differences give the population in the band as PHT (line 68), double precision being employed to improve accuracy. First and second moments are found assuming the band contents to lie at the band center.

For the load calculations, the resulting values are integrated to give PXL, the probability of exceeding X; the integration is actually formed by subtracting successive increments from an initial value of unity.

For the strength calculations, the increments are stored in PXS and the cumulative probabilities stored in PRS.

Finally, the mean (BART), standard deviation (ST) and coefficient of variation (VAR) are formed, followed by the return statement at line 89.

Lines 90 through 96 are provided to remove a possible anomaly when family B is to be subtracted. If the cumulative probability reduces in passing from one band to the next, a negative population is implied for that band, which is physically absurd. The presence of this irrational value is detected by a near zero increase in the transformed probability, YT (line 59). When such a condition occurs, BETAB is raised by five per cent and a new attempt made; this is repeated until valid results are obtained.

```
      FTI=-1000.                                                   STPR0587
      DO 5 I=1,NX                                                  STPR0588
      IF(K) 6,99,7                                                 STPR0589
    6 X2=X(I)*K                                                    STPR0590
      X1=(X(I)-DX)*K                                               STPR0591
      GO TO 40                                                     STPR0592
    7 X1=X(I)                                                      STPR0593
      X2=X1+DX                                                     STPR0594
   40 YA=(X1-XINT)/DELTAA                                          STPR0595
      FA=GLV(YA)                                                   STPR0596
      IF(ABS(SUMB)-.0001) 12,12,11                                 STPR0597
   11 YB=(X1-XINT)/DELTAB                                          STPR0598
      FB=GLV(YB)                                                   STPR0599
      GO TO 14                                                     STPR0600
   12 FB=0.0                                                       STPR0601
   14 FT=FA*SUMA+FB*SUMB                                           STPR0602
      IF(SUMA+.0001) 15,16,16                                      STPR0603
   15 IF(FT-1.E-10) 17,17,18                                       STPR0604
   17 YT=-1000.                                                    STPR0605
      GO TO 19                                                     STPR0606
   18 SLV=ONE-FT                                                   STPR0607
      IF(SLV-1.E-10) 20,20,21                                      STPR0608
   20 YT=1000.                                                     STPR0609
      GO TO 19                                                     STPR0610
   21 YT=-ALOG(ABS(ALOG(FT)))                                      STPR0611
   19 IF(YT-YTI-.01) 22,16,16                                      STPR0612
   16 YAA=(X2-XINT)/DELTAA                                         STPR0613
      FAA=GLV(YAA)                                                 STPR0614
      IF(ABS(SUMB)-.0001) 27,27,26                                 STPR0615
   26 YBB=(X2-XINT)/DELTAB                                         STPR0616
      FBB=GLV(YBB)                                                 STPR0617
      GO TO 29                                                     STPR0618
   27 FBB=0.0                                                      STPR0619
   29 FTT=FAA*SUMA+FBB*SUMB                                        STPR0620
      PI=PDENS(FTT-FT)                                             STPR0621
      SUMP=SUMP+PI                                                 STPR0622
      XM=X(I)+.5*DX*K                                              STPR0623
      SUMPX=SUMPX+PI*XM                                            STPR0624
      SUMX2=SUMX2+PI*XM*XM                                         STPR0625
      IF(K) 31,99,33                                               STPR0626
   33 PS(I)=PI                                                     STPR0627
      PS(I)=SUMP-PI                                                STPR0628
      IF(PS(I)-1.E-8) 45,5,5                                       STPR0629
   45 PS(I)=0.                                                     STPR0630
      GO TO 5                                                      STPR0631
   31 IF(I-1) 41,42,41                                             STPR0632
   42 PC(I)=1.0                                                    STPR0633
      PA=PI                                                        STPR0634
      GO TO 5                                                      STPR0635
   41 PA=PA+PI                                                     STPR0636
      PC(I)=PA                                                     STPR0637
    5 CONTINUE                                                     STPR0638
      XMEAN=SUMPX/SUMP                                             STPR0639
      SIG=SQRT((SUMX2-SUMP*XMEAN*XMEAN)/SUMP)                      STPR0640
      SKEW=SIG/XMEAN                                               STPR0641
      RETURN                                                       STPR0642
   22 DELTAA=1.75*DELTAA                                           STPR0643
      WRITE(6,100) DELTAA                                          STPR0644
  100 FORMAT(5X,*DELTAA RESET TO *,F9.3)                           STPR0645
      GO TO 4                                                      STPR0646
   99 WRITE(6,101) K                                               STPR0647
  101 FORMAT(5X,*ERROR IN CALL TO GVPR, K= *,I3)                   STPR0648
      RETURN                                                       STPR0649
      END                                                          STPR0650
```

d) STR

This routine evaluates the resultant strength distribution, PXS, and its cumulative probability, PRS, given a distribution of mean strengths, PSM2, and a basic definition of the shape of a distribution with a given mean.

Lines 1 through 7 define the basic storage, etc. and the initial values of the working arrays PXS2 and PRS2.

The loop of lines 8 through 30 takes each mean strength level in turn and forms the distribution of that contribution to the total, using EVP. The inner loop of lines 21 through 29 sums the contributions of each sub-distribution.

The second phase, lines 32 through 57, permits the superimposition of a second variation such as that due to fabrication, and reforms the values of PXS2 and PRS2.

The remaining lines sum the total and the first and second moments, form the overall mean (BART), standard deviation (ST) and coefficient of variation (VART) and also copy the working arrays into the common arrays, PXS and PRS, before returning.

```
      SUBROUTINE STR(ANS,ABARA,AVARA,ASUMB,ABARB,AVARB,ABAR,
     1BBARA,BVARA,BSUMB,BBARB,BVARB,BART,VART)
      DIMENSION PAS2(200),PPS2(200),PAT(200)
      COMMON /A/ PA(200),X(200),NA,PAS(200),PKS(200),PSH(200),PSH2(200)
      DO 8 I=1,NA
      PAS2(I)=0.
    8 PKS2(I)=0.
      DO 1 I=1,NA
      IF(PSH2(I)-(1E-10)) 12,12,2
   12 PSH2(I)=0.
      GO TO 1
    2 ABARA=ABARA*X(I)/ABAR
      ABARB=ABARB*X(I)/ABAR
      IF(ANS-1) 3,3,4
    3 SSTA=AVARA*ABARA
      SSTB=AVARB*ABARB
      GO TO 19
    4 SSTA=AVARA
      SSTB=AVARB
   19 CALL EVP(-1,ANS,ABARA,SSTA,ASUMB,ABARB,SSTB,BART,VARF)
   13 DO 5 J=1,NA
      IF(PA(J)*X(I)-10) 15,15,6
   15 DPA=0.
      GO TO 16
    6 DPA=PAS(J)*PSH2(I)
   16 DPK=PKS(J)*PSH2(I)
      PAS2(J)=PAS2(J)+DPA
      PKS2(J)=PKS2(J)+DPK
    5 CONTINUE
    1 CONTINUE
      IF(BVARA-.001) 20,21,21
   21 DO 22 I=1,NA
      PAT(I)=PAS2(I)
      PAS2(I)=0.
   22 PKS2(I)=0.
      DO 23 I=1,NA
      IF(PAT(I)-(1E-10)) 24,24,25
   24 PAT(I)=0.
      GO TO 23
   25 [illegible]
      [illegible]
      IF(ANS-1) 26,26,27
   26 [illegible]
      [illegible]
      GO TO 28
   27 [illegible]
      [illegible]
   28 CALL [illegible]
      DO [illegible]
      IF[illegible] 30,30,31
   30 [illegible]
      GO TO [illegible]
   31 [illegible]
   32 [illegible]
      [illegible]
   29 [illegible]
   23 CONTINUE
   20 [illegible]
      [illegible]
      [illegible]
      DO 7 [illegible]
      [illegible]
      [illegible]
      [illegible]
   30 [illegible]
    6 [illegible]
      [illegible]
    7 [illegible]
      [illegible]
      [illegible]
      [illegible]
      RETURN
      END
```

e) PROBF

This routine calculates the incremental probability of failure (DELPF) for each strength level and integrates to give the cumulative failure risk, PF. The final value of PF is subtracted from unity to form the reliability. The routine is also used to print all relevant output values.

Dimensions, etc. are specified in lines 1 through 20. If the output code, IP, is not zero, the heading is printed (line 22). If IP is negative, the start control, JST, is set to one, otherwise it is set to the last interval having a load probability of unity (lines 26-32). For the first interval (which will always have unity for load probability) the cumulative strength probability is used to form the total probability of failure at this load; the values are stored for plotting and are written at line 45.

The remaining intervals are then treated in turn in the loop (lines 46 through 74). When IP is +1, the insignificant lines are not printed; these are chosen as those for which the incremental failure probability is less than 10^{-11} and for which the probability of a lesser strength exceeds 0.999995. The last line is always printed. The resultant reliability is set by line 73, load levels below unfactored load being jumped.

```
      SUBROUTINE PROBF(NST,NI,NP,IP)                                    STPR0724
C         FORMS AND PRINTS PROB. OF FAILURE WHEN STRENGTH IS X          STPR0725
      COMMON /A/ PXL(200),X(200),NX,PXS(200),PRS(200),PSH(200),PSH2(200)STPR0726
      COMMON/DATA/UNFLD,FS,DX,RNB,RKML,LBARA,LVARA,LSUMB,LBARB,LVARB,   STPR0727
     1SALL,MS,OSHLD,RKS,RKMS  BARA,SVARA,SSUMB,SBARB,SVARB,FBARA,FVARA, STPR0728
     2FSUMB,FBARB,FVARB,RKE,PF1,PPU1,PF2,PPU2,RKT,RNT,T(10)             STPR0729
     6  ,XMIN , TXI(96)                                                 STPR0730
     7 ,IPLOT                                                           STPR0731
C****                                                                   STPR0732
C          COMMON FOR CALCOMP PLOTS                                     STPR0733
      COMMON /COMPLT/ XPLTT(402),YPLTT(402),YPLTB(202),XPLTB(202)       STPR0734
     1 ,BUFR,HDGC,F126,F132,F22,HLIN1P,HLIN2P,                          STPR0735
     2 HLIN3P,HLIN4P,EBUF(50)                                           STPR0736
      DIMENSION LBUF(50)                                                STPR0737
      EQUIVALENCE (EBUF(1),LBUF(1))                                     STPR0738
      DOUBLE PRECISION ONE                                              STPR0739
C****                                                                   STPR0740
C          FOR BOTTOM PLOTS                                             STPR0741
      DIMENSION BUFR (12),HDGC(19),F126(3),F132(13),                    STPR0742
     1 F22(69),HLIN1P(8),HLIN2P(8),HLIN3P(8),HLIN4P(6)                  STPR0743
      IF(IP) 20,21,20                                                   STPR0744
   20 WRITE(NP,10)                                                      STPR0745
   10 FORMAT(2X,'I',6X,'X',8X,'PXL',8X,'PXS',8X,'PRS',7X,'DELPF',       STPR0746
     18X,'PF',7X,'PSH')                                                 STPR0747
   21 ONE=1.                                                            STPR0748
      IF(IP) 25,26,26                                                   STPR0749
   25 JST=1                                                             STPR0750
      TXL=1.                                                            STPR0751
      GO TO 24                                                          STPR0752
   26 JST=NST                                                           STPR0753
      TXL=PXL(JST)                                                      STPR0754
   24 IST=JST+1                                                         STPR0755
      DELPF=TXL*PRS(JST)                                                STPR0756
      PF=DELPF                                                          STPR0757
      IF (IPLOT .EQ. 0) GO TO 4000                                      STPR0758
      XPLTT(1)=X(JST)                                                   STPR0759
      XPLTT(2)=X(JST)                                                   STPR0760
      XPLTB(1)=X(JST)                                                   STPR0761
      YPLTT(1)=DELPF                                                    STPR0762
      YPLTB(1)=PF                                                       STPR0763
      IPLT=2                                                            STPR0764
      L=1                                                               STPR0765
 4000 CONTINUE                                                          STPR0766
      IF(IP) 22,23,22                                                   STPR0767
   22 WRITE(NP,11) JST,X(JST),TXL,PXS(JST),PRS(JST),DELPF,PF,PSH2(JST)  STPR0768
   23 DO 1 I=IST,NX                                                     STPR0769
      IF(I-NST) 27,28,28                                                STPR0770
   27 DELPF=PXS(I)                                                      STPR0771
      TXL=1.0                                                           STPR0772
      GO TO 29                                                          STPR0773
   28 TXL=PXL(I)                                                        STPR0774
      DELPF=TXL*PXS(I)                                                  STPR0775
   29 PF=PF+DELPF                                                       STPR0776
      IF (IPLOT .EQ. 0) GO TO 4001                                      STPR0777
      L=L+1                                                             STPR0778
      YPLTB(L)=PF                                                       STPR0779
      YPLTT(IPLT)=DELPF                                                 STPR0780
      IPLT=IPLT+1                                                       STPR0781
      XPLTT(IPLT)=X(I)                                                  STPR0782
      YPLTT(IPLT)=DELPF                                                 STPR0783
      IPLT=IPLT+1                                                       STPR0784
      XPLTT(IPLT)=X(I)                                                  STPR0785
      XPLTB(L)=X(I)                                                     STPR0786
 4001 CONTINUE                                                          STPR0787
      IF(IP) 4,3,5                                                      STPR0788
    5 IF(DELPF-.1E-10) 6,6,4                                            STPR0789
    6 IF(ONE-PRS(I)-.1E-5) 7,7,4                                        STPR0790
    7 PRS(I)=ONE                                                        STPR0791
      IF(I-NX) 3,4,4                                                    STPR0792
    4 WRITE(NP,11) I,X(I),TXL,PXS(I),PRS(I),DELPF,PF,PSH2(I)            STPR0793
   11 FORMAT(4X,I3,F10.3,6E11.6)                                        STPR0794
    3 IF(I-NI-1) 1,1,31                                                 STPR0795
   31 ARL=ONE-PF                                                        STPR0796
```

e) PROBF (Concluded)

The final lines print the total failure probability and reliability, storing the values for plotting before returning.

f) BLKDAT

This subroutine stores the titles used in the plot routine.

```
    1 CONTINUE                                                          STPR0797
      WRITE (NP,12) ARL,PF                                              STPR0798
   12 FORMAT(5X,                                                        STPR0799
     2            'ASYMPTOTIC RELIABILITY INDEX IS ',F10.7,5X,'FAILURE',STPR0800
     3' PROB. =',E13.7/)                                                STPR0801
      IF (IPLOT .EQ. 0) GO TO 4002                                      STPR0802
      ENCODE (EBUF,5002) ARL                                            STPR0803
      HLIN4P(5)=EBUF(1)                                                 STPR0804
      HLIN4P(6)=EBUF(2)                                                 STPR0805
      HLIN4P(7)=EBUF(3)                                                 STPR0806
      HLIN4P(8)=EBUF(4)                                                 STPR0807
 5002 FORMAT (F10.7)                                                    STPR0808
 4002 CONTINUE                                                          STPR0809
      RETURN                                                            STPR0810
      END                                                               STPR0811
```

```
      BLOCK DATA                                                        STPR0812
C....                                                                   STPR0813
C           BLOCK DATA SUBPROGRAM TO CONTAIN TITLES                     STPR0814
C           FOR CALCOMP PLOTS                                           STPR0815
      COMMON /COMPLT/ XPLTT(402),YPLTT(402),YPLTB(202),APLTA(202)       STPR0816
     1 ,BUFR,HDGC,F126,F132,F22,HLIN1P,HLIN2P,                          STPR0817
     2  HLIN3P,HLIN4P                                                   STPR0818
      DIMENSION BUFR (12),HDGC(19),F126(3),F132(13),                    STPR0819
     1 F22(69),HLIN1P(8),HLIN2P(8),HLIN3P(8),HLIN4P(8)                  STPR0820
      DIMENSION E22(9)                                                  STPR0821
      EQUIVALENCE (F22(1),E22(1))                                       STPR0822
      DATA (HDGC(I),I=1,3)/'CASL NO.            '/                      STPR0823
      DATA F126 /'TEST SERIES        '/                                 STPR0824
      DATA F132 /'TEST NO.           TEST FACTOR             TEST LOAD  STPR0825
     1                   '/                                             STPR0826
      DATA HLIN1P /'UNFACTORED LOAD       =                      '/     STPR0827
      DATA HLIN2P /'UNDERSTRENGTH RISK    =                      '/     STPR0828
      DATA HLIN3P /'RELIABILITY INDEX     =                      '/     STPR0829
      DATA HLIN4P /'ASYMPTOTIC REL. INDEX =                      '/     STPR0830
      DATA E22 /'PROB. OF SURVIVING NEXT TESTS  TEST   LOAD      PROB. 'STPR0831
     1/                                                                 STPR0832
      END                                                               STPR0833
```

9. SUBPLT

This is used in conjunction with th system routines PLOT, PLOTS, SCALE, CAXIS, SYMBOL and LINE, to plot the appropriate output. Values are written on magnetic tape for eventual preparation of hard-copy output.

```
      SUBROUTINE SUBPLT (IPLT,NX)                                        STPR0834
      COMMON /COMPLT/ XPLTT(402),YPLTT(402),YPLTB(202),XPLTB(202)        STPR0835
     1 ,BUFR,HOGC,F126,F132,F22,HLIN1P,HLIN2P,                           STPR0836
     2 HLIN3P,HLIN4P,EBUF(50)                                            STPR0837
      DIMENSION BUFR (12),HOGC(19),F126(3),F132(13),                     STPR0838
     1 F22(69),HLIN1P(8),HLIN2P(8),HLIN3P(8),HLIN4P(8)                   STPR0839
      DIMENSION BUFFER(1024), IDENT(5)                                   STPR0840
      DATA IDENT / ' 5079.700  07-14   BRT05/      '/,BLANK /'       '/  STPR0841
      DATA XAXIS /'X'/, YAXISB /'P(F)'/, YAXIST /'DP(F)'/                STPR0842
      IF (LPLOT .LT. 0) GO TO 7930                                       STPR0843
C****                                                                    STPR0844
C          INITIALIZE PLOT PACKAGE                                       STPR0845
      IN4=4                                                              STPR0846
      CALL PLOTS (BUFFER,1024,IN4,IDENT,30)                              STPR0847
      LPLOT=-1                                                           STPR0848
 7930 CONTINUE                                                           STPR0849
      CALL PLOT (0.0,0.0,-2)                                             STPR0850
C****                                                                    STPR0851
C          GET MIN. X AND DELTA X - SAME FOR TOP AND BOTTOM PLOTS        STPR0852
      CALL SCALE (XPLTB,8.0,NX,1)                                        STPR0853
      INCTOP=NX+2                                                        STPR0854
      XPLTT(INCTOP+1)=XPLTB(NX+1)                                        STPR0855
      DXPLT=XPLTB(NX+2)                                                  STPR0856
      XPLTT(INCTOP+2)=XPLTB(NX+2)                                        STPR0857
      XMINPL=XPLTB(NX+1)                                                 STPR0858
C****                                                                    STPR0859
C          MIN. Y AND DELTA Y FOR BOTTOM AND TOP PLOTS                   STPR0860
      CALL SCALE (YPLTB,3.5,NX,1)                                        STPR0861
      YMINPB=YPLTB(NX+1)                                                 STPR0862
      DYB=YPLTB(NX+2)                                                    STPR0863
      CALL SCALE (YPLTT,3.5,NX+2,1)                                      STPR0864
      YMINPT=YPLTT(INCTOP+1)                                             STPR0865
      DYT=YPLTT(INCTOP+2)                                                STPR0866
      CALL CAXIS(0.0,0.0,XAXIS,-1,8.0,0.0,XMINPL,DXPLT,0.10,-1)          STPR0867
      CALL CAXIS(0.0,0.0,YAXISB,4,3.5,90.0,YMINPB,DYB,0.10,2)            STPR0868
      CALL SYMBOL (3.5,3.4,0.10,HLIN4P,0.0,48)                           STPR0869
      IF (IPLT .EQ. 0) GO TO 20                                          STPR0870
      CALL SYMBOL (1.0,10.1,0.10,F132,0.0,60)                            STPR0871
      CALL SYMBOL (4.5,9.3,0.10,F22,0.0,30)                              STPR0872
      CALL SYMBOL (4.7,9.2,0.10,F22(6),0.0,24)                           STPR0873
      DYR=0.3                                                            STPR0874
      Y=8.9                                                              STPR0875
      IJ=13                                                              STPR0876
      DO 15 I=1,IPLT                                                     STPR0877
      CALL SYMBOL (4.7,Y,0.10,F22(IJ),0.0,30)                            STPR0878
      IJ=IJ+5                                                            STPR0879
      Y=Y-DYR                                                            STPR0880
   15 CONTINUE                                                           STPR0881
   20 CONTINUE                                                           STPR0882
C****                                                                    STPR0883
C          MAKE BOTTOM PLOT                                              STPR0884
      CALL LINE (XPLTB,YPLTB,NX,1,0,29)                                  STPR0885
C****                                                                    STPR0886
C          PUT AXIS ON TOP PLOT AND DRAW IT                              STPR0887
      CALL CAXIS(0.0,5.0,XAXIS,-1,8.0,0.0,XMINPL,DXPLT,0.10,-1)          STPR0888
      CALL CAXIS(0.0,5.0,YAXIST,5,3.5,90.0,YMINPT,DYT,0.10,2)            STPR0889
C****                                                                    STPR0890
C     PUT ON PAGE HEADINGS                                               STPR0891
      CALL SYMBOL (1.0,10.5,0.10,HOGC,0.0,40)                            STPR0892
      CALL SYMBOL (1.0,10.3,0.10,HOGC(9),0.0,44)                         STPR0893
      CALL SYMBOL (3.5,9.9,0.10,BUFR(1),0.0,36)                          STPR0894
      CALL SYMBOL (3.5,9.7,0.10,BUFR(7),0.0,36)                          STPR0895
C****                                                                    STPR0896
C     REORIGIN FOR TOP PLOT                                              STPR0897
      CALL PLOT(0.0,5.0,-3)                                              STPR0898
      CALL LINE (XPLTT(2),YPLTT(2),INCTOP-1,1,0,29)                      STPR0899
      RETURN                                                             STPR0900
      END                                                                STPR0901
```

h) DISCR

This routine uses the appropriate error functions to modify the mean strength distribution array, PSM. It contains four alternatives, described in Appendix II.

Lines 1 through 7 set the storage, etc. and the program then splits four ways.

If KE is 1, the Bouton/Jablecki function is formed and used to define the probable PSM values, as implied by lines 9 through 23.

When KE is 2, the Freudenthal function is used in the same way (lines 24 through 37).

For a KE of 3, a Gumbel function is used (lines 38 through 51). The fourth option differs in using a double-family distribution whose means and coefficients of variation are input. Lines 52 through 72 are similar to the corresponding parts of EVP and also form a modified PSM array.

```
      SUBROUTINE DISCRI(KE,KSTOP,NP)
      COMMON /A/ PXL(200),X(200),NX,PXS(200),PRS(200),PSH(200),PSH2(200)
      COMMON/DATA/UNFLD,FS,DX,RNB,RKHL,LBARA,LVARA,LSUMB,LBARB,LVARB,
     1SALL,MS,DSNLD,RKS,RKHS,SBARA,SVARA,SSUMB,SBARB,SVARB,FBARA,FVARA,
     2FSUMB,FBARB,FVARB,RKE,PF1,PPU1,PF2,PPU2,RKT,RNT,I(10)
      REAL LBARA,LVARA,LSUMB,LBARB,LVARB,MS
      DOUBLE PRECISION PR1,PR2,PA1,PA2,PB1,PB2,GEV
      GO TO (2,3,1,16), KE
    2 A=10.**((ALOG10(PF2)*ALOG10(PPU1)-ALOG10(PF1)*ALOG10(PPU2))/
     1(ALOG10(PF2)-ALOG10(PF1)))
      RA=1./A
      RI=(ALOG10(PF2)-ALOG10(PF1))/(ALOG10(PPU2)-ALOG10(PPU1))
      DO 4 I=1,NX
      PR1=(RA*(X(I)-.5*DX)/DSNLD)**RI
      IF(PR1-1.0) 8,5,5
    8 PR2=(RA*(X(I)+.5*DX)/DSNLD)**RI
      IF(PR2-1.0) 12,13,13
   13 PR2=1.0
   12 PSH(I)=ABS(PR1-PR2)
      IF(PSH(I)-.1E-10) 5,5,4
    5 PSH(I)=0.0
    4 CONTINUE
      GO TO 20
    3 RI=(ALOG10(-ALOG(1.0-PF2))-ALOG10(-ALOG(1.0-PF1)))/
     1(ALOG10(PPU2)-ALOG10(PPU1))
      RA=((-ALOG(1.0-PF1))**(1./RI))/PPU1
      DO 6 I=1,NX
      PR1=EXP(-(RA*(X(I)-.5*DX)/DSNLD)**RI)
      IF(PR1-1.0) 9,7,7
    9 PR2=EXP(-(RA*(X(I)+.5*DX)/DSNLD)**RI)
      IF(PR2-1.0) 14,19,19
   19 PR2=1.0
   14 PSH(I)=ABS(PR1-PR2)
      IF(PSH(I)-.1E-10) 7,7,6
    7 PSH(I)=0.0
    6 CONTINUE
      GO TO 20
    1 A1=ALOG(ABS(ALOG(1.0-PF1)))
      A2=ALOG(ABS(ALOG(1.0-PF2)))
      PMEAN=((A1+.57722)*PPU2-(A2+.57722)*PPU1)/(A1-A2)
      S=(1.28255*(PPU1-PMEAN))/(A1+.57722)
      DO 10 I=1,NX
      Y1=.57722+1.28255*(PMEAN-(X(I)-.5*DX)/DSNLD)/S
      Y2=Y1-1.28255*DX/(DSNLD*S)
      PR1=GEV(Y1)
      PR2=GEV(Y2)
      PSH(I)=DABS(PR1-PR2)
      IF(PSH(I)-.1E-10) 11,11,10
   11 PSH(I)=0.0
   10 CONTINUE
      GO TO 20
   16 [illegible]=PF1
      [illegible]=PPU1
      SUMB=PF2
      [illegible]=PPU2
      STA=[illegible]
      STB=[illegible]
      DO 18 I=1,NX
      Y1=1.28255*[illegible].57722
      Y2=Y1-1.28255*DX/STA
      PA1=GEV(Y1)
      PA2=GEV(Y2)
      PA=[illegible]DABS(PA1-PA2)
      IF(ABS(STB)-[illegible]) 17,17,18
   17 PB=0.0
      GO TO [illegible]
   18 Y1=1.28255*[illegible].57722
      Y2=Y1-1.28255*DX/STB
      PB1=GEV(Y1)
      PB2=GEV(Y2)
      PB=SUMB*DABS(PB1-PB2)
   50 PSH(I)=PA+PB
```

h) DISCR (Concluded)

The final lines are common to all four options and are a test that virtually all of the distribution has been formed within the permitted X-range.

i) TEST

This routine evaluates the chances of surviving each of the subsequent tests in a series. Lines 1-20 set the storage locations and write the heading.

For NT tests to each specified (non-zero) test factor, lines 22 through 50 locate the band containing the test load, XT and extract the probability of strength less than this. The complement gives the required chance which is self-multiplied for each test in the series (line 33). Values are written and stored for the plot routine before ret..ning at line 50.

```
   20 SUM=0.                                                          STPR0974
      DO 21 I=1,NX                                                    STPR0975
   21 SUM=SUM+PSH(I)                                                  STPR0976
      IF(SUM-.95) 22,22,23                                            STPR0977
   22 WRITE(NP,24) SUM                                                STPR0978
   24 FORMAT(3X,'X-RANGE INSUFFICIENT TO COVER MEAN STRENGTH',        STPR0979
     15X,'SUM =',E11.5)                                               STPR0980
      KSTOP=1                                                         STPR0981
   23 RETURN                                                          STPR0982
      END                                                             STPR0983
```

```
      SUBROUTINE TEST(KT,XT,NP,J,NT,DX,KSTOP,UNFLD,T,PR,NX,X,IPLOT)   STPR0984
      COMMON /COMPLT/ XPLTT(402),YPLTT(402),YPLT8(202),APLT8(202)     STPR0985
     1 ,BUFR,HOGC,F126,F132,F22,HLIN1P,HLIN2P,                        STPR0986
     2 HLIN3P,HLIN4P,EBUF(50)                                         STPR0987
      DIMENSION LBUF(50)                                              STPR0988
      EQUIVALENCE (EBUF(1),LBUF(1))                                   STPR0989
      DIMENSION IF22(10)                                              STPR0990
      DIMENSION BUFR (12),HOGC(19),F126(3),F132(13),                  STPR0991
     1 F22(69),HLIN1P(8),HLIN2P(8),HLIN3P(8),HLIN4P(8)                STPR0992
      DIMENSION T(10),PR(200),X(200)                                  STPR0993
      EQUIVALENCE (F22(1),IF22(1))                                    STPR0994
      DATA BLANK /6H      /                                           STPR0995
      DO 100 I=10,69                                                  STPR0996
  100 F22(I)=BLANK                                                    STPR0997
      IHRT=10                                                         STPR0998
 6000 FORMAT (I2)                                                     STPR0999
 6001 FORMAT (F8.3)                                                   STPR1000
      WRITE(NP,20)                                                    STPR1001
   20 FORMAT( 5X,'PROBABILITY OF SURVIVING NEXT TEST(S)',6X,'TEST',4X,STPR1002
     1,'LOAD',7X,'PROB.')                                             STPR1003
      GO TO (10,11,11),KT                                             STPR1004
   10 DO 1 I=1,NX                                                     STPR1005
      IF(X(I)+DX/2.-XT) 1,2,2                                         STPR1006
    2 IJ=I                                                            STPR1007
      GO TO 3                                                         STPR1008
    1 CONTINUE                                                        STPR1009
    5 WRITE(NP,21)                                                    STPR1010
   21 FORMAT(8X,'TEST LOAD TOO HIGH FOR X-RANGE.  CASE ENDED.')       STPR1011
      KSTOP=1                                                         STPR1012
      RETURN                                                          STPR1013
    3 DO 4 I=J,NT                                                     STPR1014
      N=I-J+1                                                         STPR1015
      PT=(1.-PR(IJ))**N                                               STPR1016
      IF (IPLOT .EQ. 0) GO TO 4                                       STPR1017
      ENCODE (LBUF,6000) I                                            STPR1018
      IF22(IHRT)=LBUF(1)                                              STPR1019
      ENCODE (EBUF,6001) XT                                           STPR1020
      IHRT=IHRT+1                                                     STPR1021
      F22(IHRT)=EBUF(1)                                               STPR1022
      IHRT=IHRT+1                                                     STPR1023
      F22(IHRT)=EBUF(2)                                               STPR1024
      ENCODE (EBUF,6001) PT                                           STPR1025
      IHRT=IHRT+1                                                     STPR1026
      F22(IHRT)=EBUF(1)                                               STPR1027
      IHRT=IHRT+1                                                     STPR1028
      F22(IHRT)=EBUF(2)                                               STPR1029
      IHRT=IHRT+1                                                     STPR1030
    4 WRITE(NP,22) I,XT,PT                                            STPR1031
   22 FORMAT (48X,I2,2X,F10.3,F8.3)                                   STPR1032
      RETURN                                                          STPR1033
```

i) TEST (Concluded)

Lines 51 through 78 perform a similar function for the alternative options of one test to each of NT different test loads.

j) GEV

This function evaluates F = exp (-exp(-y)) for the Gumbel distribution. Double precision is used, and four ranges of y are separated. For $y < -4.0$, the probability of a lesser value is negligible. For values between -4.0 and 14.0, the basic function is computed. When y exceeds 30, the probability has reached an effective limit of unity.

For values between 14 and 30, direct computation breaks down since exp (-y) becomes insignificant. Expanding gives

$$e^{-e^{-y}} = 1-e^{-y} + \frac{e^{-2y}}{2!} - \frac{e^{-3y}}{3!} + \frac{e^{-4y}}{4!} - \cdots \qquad \text{A3-1}$$

but since y is large, all but the first two terms tend to zero, and the function can be replaced by 1-exp(-y).

k) BAYES

Subroutine BAYES uses Bayesian techniques to update the mean strength distribution, PSM2, so as to incorporate the test results.

Lines 1 through 18 allocate storage, etc. and initialize values. The basic loop (lines 19 through 45) first forms the constants of the double-family distribution of strength with mean at x(i). For survival tests (KT = 1), the probability of a value greater than X_T is formed at lines 25-26 and 32-36. For failure tests (KT = 2), the probability that the test load is in the interval x $\pm$ 1/2dx is formed by lines 28-36 and 38-41.

Line 42 forms the numerator of the fraction on the right hand side of equations A2-48 or A2-50, the PSXT value being appropriate to the type of test. Lines 43 and 44 determine the maximum value of the numerators for all bands, and line 45 sums the values to set the denominator.

If the denominator is "zero", lines 47-50 set a diagnostic message, and, if the summation consists essentially of one term, lines 51-56 print an appropriate warning. If a valid expression exists, lines 57-59 form the posterior distribution of mean strength as PSM2.

```
      SUBROUTINE BAYES(IFT,XT,KSTOP,NP)
      COMMON /A/ PAL(200),X(200),XX,PAS(200),FRS(200),PSH1(200),PSH2(200)
      COMMON/DATA/UNFLD,FS,DX,RHO,HKHL,LBARA,LVARA,LSUMB,LBARB,LVARB,
     1SALL,MS,DSHLD,HKS,RKHS,SBARA,SVARA,SSUMB,SBARB,SVARB,FBARA,FVARA,
     2FSUMB,FBARB,FVARB,RCE,PF1,PPU1,PF2,PPU2,RKT,RHT,T(13)
     3 ,IPLOT
      REAL LBARA,LVARA,LSUMB,LBARB,LVARB,MS
      DOUBLE PRECISION FA,FB,PSAT,PSA,GEV,ONE
      DIMENSION PRM2(200)
      SUM=0.
      ONE=1.
      SSUMA=1.0-SSUMB
      PHAT=0.
      PSA=0.
      FAA=0.
      FAB=0.0
      YAA=0.
      YBB=0.
      DO 1 I=1,NP
      BETAA=X(I)*SVARA/1.28255
      BETAB=X(I)*SVARB/1.28255
      AINTA=X(I)+.57722*BETAA
      AINTB=X(I)+.57722*BETAB
      GO TO (2,3), KT
    2 [illegible]
      [illegible]
      GO TO 4
    3 [illegible]
      [illegible]
      [illegible]
      [illegible]
    4 [illegible]
      [illegible]
      [illegible]
      [illegible]
    5 [illegible]
    7 GO TO (10,11), KT
   11 [illegible]
      [illegible]
      [illegible]
      [illegible]
   12 [illegible]
      [illegible]
    6 [illegible]
    1 SUM=SUM+PRM2(I)
      [illegible]
   12 [illegible]
      [illegible]
   21 [illegible]
      GO TO 19
   14 [illegible] 15,15,13
   15 [illegible]
      [illegible]
   22 [illegible]   CHECK VALIDITY,
     1[illegible]
      GO TO 19
   13 DO 17 I=1,NP
   17 [illegible]
   19 RETURN
      END
```

A3.5 User's Guide

a) Deck Set-up

The first two cards required are:

@ RUN Card containing run identification

@ LOG Card giving accounting information

where the symbol @ represents the multiple 7-8 punch in column 1.

The FORTRAN cards for the source decks of the main program STRP and the ten subroutines (DECRD, EVP, STR, PROBF, BLKDAT, SUBPLT, DISCR, TEST, GEV and BAYES) follow, each being preceded by an input and compile card of the form.

@ FOR, IS .STRP, .STRP

After the last routine, a card is inserted bearing

@ XQT

and, if plots are to be generated, this is preceded by

@ ASG, T 4., T, reel no.

b) Data Input

The format has been described in paragraph A3-4(b), and a sample input set is shown in Table XXXV. The first card contains the case number of the first case in the run; this is right justified to Column 5; if output device 10 is to be used, the case number is negative.

The next card bears the caption for the first case (up to 72 columns, 12A6 format being used). This card must be present. The remaining case cards bear input data which differs from the standard built-in- values. Each card carries up to five values; the location of the first is right-adjusted to column 12 and the other locations are implied as consecutive. The arithmetic values are E12 format; decimal values may lie anywhere in the 12-column field, but integers and integer exponents must be right adjusted to columns 24, 36, 48, 60 or 72. The last data card for the case must have a minus sign (-) in column 1.

TABLE XXXV

EXAMPLE OF INPUT DATA

CARD NO.	COLUMN 1 1234567890	1	2		3		4		5		6 / 7	
1	1											
2	PSD GUST LOADS											
3		5	3.0									
4		100	1.0									
5		16	102.6		.04		.25		92.		.04	
6		2[illegible]	.012		-.05		97.5					
7		27	1.0[illegible]		.05		.05		.95			
8		32	3.		1.5							
9		[illegible]	[illegible].		1.0[illegible]		.5[illegible]		.2[illegible]4		9.6[illegible]	E-2
10		[illegible]	[illegible].[illegible]7	E-2	1.03	E-2	8.[illegible]3	E-3	4.12[illegible]	E-3	1.93	E-3
11		53	9.0[illegible]	E-4	4.27	E-4	2.02	E-4	9.[illegible]	E-[illegible]	4.53	E-5
12		58	2.1[illegible]	E-[illegible]	1.62	E-[illegible]	4.87	E-[illegible]	2.3[illegible]	E-[illegible]	1.[illegible]0	E-6
13		63	3.2[illegible]	E-7	2.[illegible]	E-7	1.[illegible]	E-7	5.67	E-[illegible]	2.7[illegible]	E-3
14	PSD GUST L[illegible]											
15		2[illegible]	1.[illegible]		.0[illegible]		.05		.5			
16	[illegible]											
17		2[illegible]	.[illegible]		.0[illegible]		.1		.5			
18	PSD [illegible]											
19		2[illegible]	[illegible]									
20		[illegible]7	1.[illegible]		1.[illegible]5		.01		.3[illegible]			
21	[illegible]											
22		[illegible]	[illegible]		5.		1.5		1.5		1.5	
23		[illegible]	[illegible]		1.[illegible]		.05		.05		.05	
24	[illegible]											
25		[illegible]	1.[illegible]		.[illegible]		.05		.5			
26	[illegible]											
27		[illegible]	.[illegible]		.05		.1		.5			
28	[illegible]											
29		[illegible]	1.[illegible]		1.[illegible]		1.185		.01		.3	

A similar set of data follows for the second case (the caption, followed by any data changes, the last card having a minus sign in column 1).

Note that one data card must exist, so that when running the "standard case", at least one of the built-in values must be repeated in the input.

Referring to Table XXXV, card 3 represents data input for locations 5, 6, 7, 8, 9. Since RKML (location 5) is the only value to be changed from the built-in data, only the first data field is used, the others remaining blank. The next data item is SBARA in location 16 and cannot be entered on the same card, so a new set of five items is inserted on the next card.

Considerable flexibility exists for entering input data on the same or separate data cards. For instance, RKE started with the built-in value of 4.0, was changed to 1.0 by card 19, changed back to 4.0 by card 23 and finally changed back to 1.0 by card 29.

APPENDIX IV
EXAMPLES OF USE OF PROGRAM

A4.1 Summary

Two groups of examples are given in this Appendix, to illustrate the input and output options available. The first group uses the standard data and the second group uses realistic C-141 gust load data with realistic strength data. One of the cases in this second group was arranged to have comparable data to that required by the original program of reference 1, and the corresponding case was run using that program.

A4.2 Standard Data

The input data is shown in Table XXXVI. Three cases were run to illustrate the output options. Case 1 makes no changes to the built-in data (element 1 is repeated to provide DECRD with input); the output tables commence at line 13, the highest value of X with PXL of 1.0, and ends at the line where PRS reaches 1.0. The last line is also printed.

Case 2 calls for every line to be printed by a negative value for RNB (element 4); plotted output is requested by 1.0 at location 140. The third case restores element 140 to zero (no plots), but inputs DX as negative to call for the short output with the data and tables omitted.

The output appears in Tables XXXVII through XXXIX and the plots of case 2 are given in Figure 99.

A4.3 C-141 Examples

The input data is that of Table XXXV. Eight cases were run in sequence, the first four having three tests surviving 1.5 times the unfactored load and the last four having three test failures at that load. The error function for cases 1-3 and 5-7 was a double-family distribution, the means, coefficients of variation and contributions of the two families being varied. Cases 4 and 8 employ the standard Jablecki function of reference 1.

The output of cases 1, 4 and 8 is given in Tables XL, XLI and XLII. The plotted outputs of cases 1 and 4 are shown in Figure 100 and 101.

Table XLIII summarizes the output of all eight cases, together with the output from two runs of the original program. These used a Weibull strength

distribution (skewed towards lower strength), but whereas case 9 used a Weibull load distribution (skewed towards lower loads), case 10 used a log-normal load distribution (skewed towards higher loads) as being more representative of the data used for Case 4.

Examination of the values shows that in spite of the differences in data, in error functions and in the two programs, relatively little differences exist in the reliabilities "demonstrated" by the test results.

TABLE XXXVI

INPUT DATA FOR STANDARD CASES

CARD NO.	COLUMN 1 123456789012	2 345678901234	3 567890123456	... 7 012
1	1			
2	STANDARD DA	TA NORMAL OU	TPUT	
3	- 1	100.0		
4	STANDARD DA	TA FULL OUTP	UT	
5	140	1.0		
6	- 4	-100.0		
7	STANDARD DA	TA SHORT OUT	PUT	
8	140	0.0		
9	- 3	-5.0		

TABLE XXXVII

STANDARD CASE, NORMAL OUTPUT

```
CASE    1
STANDARD DATA, NORMAL OUTPUT

DATA
     1        2        3     4     5        6        7       8        9       10
  UNFLD      FS       DX   RNB  RKML    LBARA    LVARA   LSUMB    LBARB    LVARB
 100.000   1.50     5.00 100.   1.     80.000     .050    .000   80.000     .050

  11      12      13          14    15       16       17      18       19       20
 SALL     MS     DSNLD        RKS   RKMS    SBARA    SVARA   SSUMB    SBARB    SVARB
 2.326   .00      .000         1.    1.    150.000    .050    .000   150.000    .050

   21       22      23       24       25      26      27      28      29      30
 FBARA    FVARA   FSUMB    FBARB    FVARB    RKE     PF1    PPU1     PF2     PPU2
 100.000   .000    .000   100.000    .050     4.    1.000    .050    .000    1.000

  31    32     33     34     35     36     37     38     39     40     41     42
 RKT   PNT     T1     T2     T3     T4     T5     T6     T7     T8     T9    T10
  1.    1.   1.500   .000   .000   .000   .000   .000   .000   .000   .000   .000

LOAD DATA
UNFLD =    100.000, FS =1.500, FACLD =    150.000, MS = .000, PDSNLD =    150.000
MEAN MAX. LOAD =     80.016, VAR =   .053
```

TABLE XXXVII (CONTINUED)

INTENDED STRENGTH   AMSTR =   170.152, STS =   8.664, VARS = .051
BASIC (MATERIAL) MEAN STRENGTH =   150.000 VAR = .051

INTENDED FAILURE PROB., NO DISCREPANCY, NO TEST

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.39149-07	.73905-07	.73905-07	.73905-07	.00000
14	70.000	.93857+00	.83248-07	.15715-06	.78134-07	.15204-06	.00000
15	75.000	.42962+00	.17702-06	.33417-06	.76052-07	.22809-06	.00000
16	80.000	.10685+00	.37642-06	.71060-06	.40219-07	.26831-06	.00000
17	85.000	.22484-01	.80932-06	.15199-05	.[illegible]8197-07	.28651-06	.00000
18	90.000	.45652-02	.16987-05	.32187-05	.77568-08	.29426-06	.00000
19	95.000	.92066-03	.36210-05	.68396-05	.33337-08	.29760-06	.00000
20	100.000	.18536-03	.76964-05	.14536-04	.14266-08	.29902-06	.00000
21	105.000	.37313-04	.16361-04	.30898-04	.61049-09	.29963-06	.00000
22	110.000	.75176-05	.34802-04	.65699-04	.26163-09	.29990-06	.00000
23	115.000	.15199-05	.73992-04	.13969-03	.11246-09	.30001-06	.00000
24	120.000	.30410-06	.15732-03	.29701-03	.47841-10	.30006-06	.00000
25	125.000	.[illegible]201-07	.33443-03	.63144-03	.20468-10	.30008-06	.00000
26	130.000	.12317-07	.71079-03	.13422-02	.87549-11	.30009-06	.00000
27	135.000	.24789-08	.15098-02	.28520-02	.37425-11	.30009-06	.00000
28	140.000	.498[illegible]-09	.32028-02	.60548-02	.15978-11	.30009-06	.00000
29	145.000	.10040-09	.67764-02	.12831-01	.68036-12	.30009-06	.00000
30	150.000	.20206-10	.14256-01	.27087-01	.28307-12	.30009-06	.00000
31	155.000	.496[illegible]-11	.29634-01	.56722-01	.12051-12	.30009-06	.00000
32	160.000	.81841-12	.60049-01	.11677+00	.49145-13	.30009-06	.00000
33	165.000	.16471-12	.11529+00	.23206+00	.18988-13	.30009-06	.00000
34	170.000	.00000	.19757+00	.42962+00	.00000	.30009-06	.10000+01
35	175.000	.00000	.26734+00	.69696+00	.00000	.30009-06	.00000
36	180.000	.00000	.22407+00	.92103+00	.00000	.30009-06	.00000
37	185.000	.00000	.74[illegible]3-01	.99548+00	.00000	.30009-06	.00000
38	190.000	.00000	.45135-02	.99999+00	.00000	.30009-06	.00000
59.	295.000	.00000	.00000	.10000+01	.00000	.30009-06	.00000

ASYMPTOTIC RELIABILITY INDEX IS   .9999[illegible]7   FAILURE PROB. =   .3000925-06

TABLE XXXVII(CONTINUED)

PREDICTED FAILURE PROB., WITH PROBABLE DISCREPANCY, NO TEST
REVISED MEAN STRENGTH = 152.500, VAR = .071

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.46306-06	.77468-06	.77468-06	.77468-06	.24084-06
14	70.000	.93857+00	.11536-05	.19282-05	.10827-05	.18574-05	.57187-06
15	75.000	.42962+00	.28612-05	.47895-05	.12292-05	.30866-05	.13337-05
16	80.000	.10685+00	.70374-05	.11827-04	.75191-06	.38385-05	.31292-05
17	85.000	.22488-01	.17209-04	.29036-04	.38693-06	.42255-05	.73686-05
18	90.000	.45652-02	.41634-04	.70670-04	.19011-06	.44156-05	.17308-04
19	95.000	.92066-03	.99356-04	.17003-03	.91473-07	.45070-05	.40717-04
20	100.000	.18536-03	.23334-03	.40337-03	.43253-07	.45503-05	.95725-04
21	105.000	.37313-04	.53786-03	.94123-03	.20069-07	.45704-05	.22506-03
22	110.000	.75176-05	.12134-02	.21547-02	.91222-08	.45795-05	.52902-03
23	115.000	.15190-05	.26705-02	.48251-02	.40589-08	.45835-05	.12429-02
24	120.000	.30410-06	.57087-02	.10534-01	.17360-08	.45853-05	.29165-02
25	125.000	.61201-07	.11787-01	.22321-01	.72137-09	.45860-05	.68249-02
26	130.000	.12317-07	.23519-01	.45640-01	.28722-09	.45863-05	.15863-01
27	135.000	.24789-08	.43702-01	.89342-01	.10835-09	.45864-05	.36306-01
28	140.000	.49893-09	.76305-01	.16965+00	.38067-10	.45864-05	.80118-01
29	145.000	.10040-09	.12116+00	.28600+00	.12164-10	.45864-05	.16240+00
30	150.000	.20206-10	.16819+00	.45569+00	.34127-11	.45865-05	.27065+00
31	155.000	.40659-11	.19057+00	.65226+00	.79036-12	.45865-05	.29070+00
32	160.000	.81841-12	.17601+00	.83028+00	.14569-12	.45865-05	.12350+00
33	165.000	.16471-12	.11393+00	.94520+00	.18765-13	.45865-05	.85471-02
34	170.000	[illegible]	.45302-01	.98954+00	.00000	.45865-05	.13754-04
35	175.000	[illegible]	.96154-02	.99915+00	.00000	.45865-05	.00000
36	180.000	[illegible]	.82101-03	.99997+00	.00000	.45865-05	.00000
59	295.000	[illegible]	[illegible]	.10000+01	.00000	.45865-05	.00000

ASYMPTOTIC RELIABILITY INDEX IS .9[illegible]54 FAILURE PROB. = .4586452-05

TABLE XXXVII (CONCLUDED)

UPDATED FAILURE PROB. AFTER 1 TEST(S) TO PASS SAME LOAD

TEST SERIES 1
TEST NO. 1, TEST FACTOR =1.500, TEST LOAD = 150.000

PROBABILITY OF SURVIVING NEXT TEST(S)

TEST	LOAD	PROB.
1	150.000	.544

REVISED MEAN STRENGTH = 156.412, VAR = .058

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.12512-06	.21979-06	.21979-06	.21979-06	.00000
14	70.000	.93857+00	.29127-06	.51106-06	.27338-06	.49317-06	.00000
15	75.000	.42962+00	.68239-06	.11933-05	.29313-06	.78629-06	.00000
16	80.000	.10685+00	.15772-05	.27705-05	.16851-06	.95481-06	.00000
17	85.000	.22484-01	.36373-05	.64378-05	.82456-07	.10373-05	.00000
18	90.000	.45642-02	.85615-05	.14989-04	.39048-07	.10763-05	.00000
19	95.000	.92060-03	.19943-04	.34932-04	.18361-07	.10947-05	.00000
20	100.000	.18536-03	.46559-04	.81492-04	.86303-08	.11033-05	.00000
21	105.000	.37313-04	.10875-03	.19024-03	.40578-08	.11074-05	.00000
22	110.000	.75176-05	.25416-03	.44440-03	.19107-08	.11093-05	.00000
23	115.000	.15199-05	.59417-03	.10386-02	.90310-09	.11102-05	.00000
24	120.000	.30413-06	.13899-02	.24274-02	.42235-09	.11106-05	.00000
25	125.000	.61201-07	.32416-02	.56590-02	.19839-09	.11108-05	.00000
26	130.000	.12317-07	.75308-02	.13200-01	.92757-10	.11109-05	.00000
27	135.000	.24789-08	.17285-01	.30484-01	.42846-10	.11109-05	.40574-05
28	140.000	.490[illegible]-09	.3852[illegible]-01	.69036-01	.19218-10	.11109-05	.46102-02
29	145.000	.10040-09	.80370-01	.14938+01	.80693-11	.11110-05	.76599-01
30	150.000	.20206-10	.14707+00	.29646+00	.29717-11	.11110-05	.28361+00
31	155.000	.406[illegible]-11	.21589+01	.51233+00	.87793-12	.11110-05	.41783+00
32	160.000	.81[illegible]-12	.23216+00	.74449+00	.19000-12	.11110-05	.20265+00
33	165.000	.16871-12	.16171+00	.91120+00	.27459-13	.11110-05	.14870-01
34	170.000	.0[illegible]	.71477-01	.98265+00	.00000	.11110-05	.24584-04
35	175.000	.0[illegible]	.15897-01	.99855+00	.00000	.11110-05	.00000
36	180.000	.[illegible]	.14059-02	.99995+00	.00000	.11110-05	.00000
59	295.000	.0[illegible]	.[illegible]	.10000+01	.00000	.11110-05	.00000

ASYMPTOTIC RELIABILITY INDEX IS .9[illegible]89 FAILURE PROB. = .1110961-05

TABLE XXXVIII

STANDARD CASE, FULL OUTPUT

CASE 2
STANDARD DATA, FULL OUTPUT

DATA

1	2	3	4	5	6	7	8	9	10
UNFLD	FS	DX	RNB	RKML	LBARA	LVARA	LSUMB	LBARB	LVARB
100.000	1.50	5.00	-100.	1.	80.000	.050	.000	80.000	.050

11	12	13	14	15	16	17	18	19	20
SALL	MS	DSNLD	RKS	RKMS	SBARA	SVARA	SSUMB	SBARB	SVARB
2.326	.00	150.000	1.	1.	150.000	.050	.000	150.000	.050

21	22	23	24	25	26	27	28	29	30
FBARA	FVARA	FSUMB	FBARB	FVARB	RKE	PF1	PFU1	PF2	PFU2
100.000	.000	.000	100.000	.050	4.	1.000	.050	.000	1.000

31	32	33	34	35	36	37	38	39	40	41	42
RKT	RNT	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
1.	1.	1.500	.000	[illegible]	.000	.000	.000	.000	.000	.000	.000

LOAD DATA
UNFLD = 100.000, FS =1.500, FACLD = 150.000, MS = .000, PDSNLD = 150.000
MEAN MAX. LOAD = 80.016, VAR = .053

INTENDED STRENGTH AMSTR = 170.152, STS = 8.664, VARS = .051
BASIC (MATERIAL) MEAN STRENGTH = 150.000 VAR = .051

TABLE XXXVIII (Continued)

INTENDED FAILURE PROB., NO DISCREPANCY, NO TEST

I	X	PXL	PXS	PRS	DELPF	PF	PSM
1	5.000	.10000+01	.00000	.86473-11	.86473-11	.86473-11	.00000
2	10.000	.10000+01	.00000	.18388-10	.00000	.86473-11	.00000
3	15.000	.10000+01	.20712-10	.39100-10	.20712-10	.29360-10	.00000
4	20.000	.10000+01	.44043-10	.83143-10	.44043-10	.73403-10	.00000
5	25.000	.10000+01	.93655-10	.17680-09	.93655-10	.16706-09	.00000
6	30.000	.10000+01	.19915-09	.37595-09	.19915-09	.36621-09	.00000
7	35.000	.10000+01	.42348-09	.79942-09	.42348-09	.78968-09	.00000
8	40.000	.10000+01	.90049-09	.16999-08	.90049-09	.16902-08	.00000
9	45.000	.10000+01	.19148-08	.36147-08	.19148-08	.36050-08	.00000
10	50.000	.10000+01	.40717-08	.76864-08	.40717-08	.76767-08	.00000
11	55.000	.10000+01	.86582-08	.16345-07	.86582-08	.16335-07	.00000
12	60.000	.10000+01	.18411-07	.34756-07	.18411-07	.34746-07	.00000
13	65.000	.10000+01	.39149-07	.73905-07	.39149-07	.73895-07	.00000
14	70.000	.93857+00	.83248-07	.15715-06	.78134-07	.15203-06	.00000
15	75.000	.42962+00	.17702-06	.33417-06	.76052-07	.22808-06	.00000
16	80.000	.10685+00	.37642-06	.71060-06	.40219-07	.26830-06	.00000
17	85.000	.22484-01	.80932-06	.15199-05	.18197-07	.28650-06	.00000
18	90.000	.45662-02	.16987-05	.32187-05	.77568-08	.29425-06	.00000
19	95.000	.92066-03	.36210-05	.68396-05	.33337-08	.29759-06	.00000
20	100.000	.18536-03	.76964-05	.14536-04	.14266-08	.29901-06	.00000
21	105.000	.37313-04	.16361-04	.30898-04	.61049-09	.29963-06	.00000
22	110.000	.75176-05	.34802-04	.65699-04	.26163-09	.29989-06	.00000
23	115.000	.15190-05	.73992-04	.13969-03	.11246-09	.30000-06	.00000
24	120.000	.30410-06	.15732-03	.29701-03	.47841-10	.30005-06	.00000
25	125.000	.61201-07	.33443-03	.63148-03	.20468-10	.30007-06	.00000
26	130.000	.12317-07	.71079-03	.13422-02	.87549-11	.30008-06	.00000
27	135.000	.24789-08	.15098-02	.28520-02	.37425-11	.30008-06	.00000
28	140.000	.498[illegible]-09	.32028-02	.60548-02	.15978-11	.30008-06	.00000
29	145.000	.10[illegible]-09	.67764-02	.12831-01	.68036-12	.30008-06	.00000
30	150.000	.20206-10	.14256-01	.27087-01	.28807-12	.30008-06	.00000
31	155.000	.406[illegible]-11	.29534-01	.56722-01	.12051-12	.30008-06	.00000
32	160.000	.81[illegible]41-12	.60049-01	.11677+00	.49145-13	.30008-06	.00000
33	165.000	.16871-12	.1[illegible]529+00	.23206+00	.18988-13	.30008-06	.00000
34	170.000	.[illegible]	.19757+00	.42962+00	.00000	.30008-06	.10000+01

TABLE XXXVIII (Continued)

35	175.000	.00000	.26734+00	.69696+00	.00000	.30008-06	.00000
36	180.000	.00000	.22407+00	.92103+00	.00000	.30008-06	.00000
37	185.000	.00000	.74[illegible]3-01	.99548+00	.00000	.30008-06	.00000
38	190.000	.00000	.45135-02	.99999+00	.00000	.30008-06	.00000
39	195.000	.00000	.10342-04	.10000+01	.00000	.30008-06	.00000
40	200.000	.00000	.25008-10	.10000+01	.00000	.30008-06	.00000
41	205.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
42	210.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
43	215.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
44	220.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
45	225.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
46	230.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
47	235.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
48	240.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
49	245.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
50	250.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
51	255.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
52	260.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
53	265.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
54	270.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
55	275.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
56	280.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
57	285.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
58	290.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000
59	295.000	.00000	.00000	.10000+01	.00000	.30008-06	.00000

ASYMPTOTIC RELIABILITY INDEX IS .9[illegible]7 FAILURE PROB. = .30[illegible]827-06

PREDICTED FAILURE PROB., WITH PROBABLE DISCREPANCY, NO TEST
REVISED MEAN STRENGTH = 152.500, VAR = .071

I	X	PXL	PXS	PRS	DELPF	PF	PSM
1	5.0	.10000+01	.19871-11	.95960-11	.95960-11	.95960-11	.00000
2	10.0	.10000+01	.21621-10	.31217-10	.21621-10	.31217-10	.19817-10
3	15.0	.10000+01	.62559-10	.93776-10	.62559-10	.93776-10	.46598-10
4	20.0	.10000+01	.14871-09	.24069-09	.14871-09	.24069-09	.10957-09
5	25.0	.10000+01	.35429-09	.59778-09	.35429-09	.59778-09	.2576[illegible]-09
6	30.0	.10000+01	.85363-09	.14513-08	.85363-09	.14513-08	.60587-09

TABLE XXXVIII (Continued)

7	35.000	.10000+01	.20625-08	.35138-08	.20625-08	.35138-08	.14247-08
8	40.000	.10000+01	.50146-08	.85285-08	.50146-08	.85285-08	.33501-08
9	45.000	.10000+01	.12270-07	.20798-07	.12270-07	.20798-07	.78775-08
10	50.000	.10000+01	.30207-07	.51005-07	.30207-07	.51005-07	.18524-07
11	55.000	.10000+01	.74777-07	.12578-06	.74777-07	.12578-06	.43557-07
12	60.000	.10000+01	.18584-06	.31162-06	.18584-06	.31162-06	.10242-06
13	65.000	.10000+01	.46306-06	.77468-06	.46306-06	.77468-06	.24084-06
14	70.000	.93857+00	.11536-05	.19282-05	.10827-05	.18574-05	.57187-06
15	75.000	.42962+00	.28612-05	.47895-05	.12292-05	.30865-05	.13537-05
16	80.000	.10685+00	.70374-05	.11827-04	.75191-06	.38385-05	.31292-05
17	85.000	.22484-01	.17209-04	.29036-04	.38693-06	.42255-05	.73685-05
18	90.000	.45632-02	.41634-04	.70670-04	.19011-06	.44156-05	.17308-04
19	95.000	.92065-03	.99356-04	.17003-03	.91473-07	.45070-05	.40717-04
20	100.000	.18536-03	.23534-03	.40337-03	.43253-07	.45503-05	.95725-04
21	105.000	.37313-04	.53786-03	.94123-03	.20069-07	.45704-05	.22506-03
22	110.000	.75176-05	.12134-02	.21547-02	.91222-08	.45795-05	.52902-03
23	115.000	.15190-05	.26705-02	.48251-02	.40589-08	.45835-05	.12429-02
24	120.000	.30410-06	.57087-02	.10534-01	.17360-08	.45853-05	.29165-02
25	125.000	.61201-07	.11787-01	.22321-01	.72137-09	.45860-05	.68245-02
26	130.000	.12317-07	.23519-01	.45640-01	.28722-09	.45863-05	.15863-01
27	135.000	.24789-08	.43702-01	.89342-01	.10833-09	.45864-05	.36306-01
28	140.000	.498[illegible]-09	.76305-01	.16565+00	.38067-10	.45864-05	.80118-01
29	145.000	.10[illegible]-09	.12116+00	.28680+00	.12164-10	.45864-05	.16240+00
30	150.000	.20206-10	.168[illegible]9+00	.45569+00	.34127-11	.45865-05	.27065+00
31	155.000	.406[illegible]-11	.19657+00	.65226+00	.79936-12	.45865-05	.29070+00
32	160.000	.81341-12	.17801+00	.83023+00	.14569-12	.45865-05	.12350+00
33	165.000	.16471-12	.11393+00	.94720+00	.18765-13	.45865-05	.85471-02
34	170.000	.0[illegible]	.45332-01	.98954+00	.00000	.45865-05	.13754-04
35	175.000	.00000	.96154-02	.99915+00	.00000	.45865-05	.00000
36	180.000	.0[illegible]	.82201-03	.99997+00	.00000	.45865-05	.00000
37	185.000	.0[illegible]	.27468-04	.10000+01	.00000	.45865-05	.00000
38	190.000	.0[illegible]	.91523-07	.10000+01	.00000	.45865-05	.00000
39	195.000	.0[illegible]	.142[illegible]-09	.10000+01	.00000	.45865-05	.00000
40	200.000	.0[illegible]	.34464-15	.10000+01	.00000	.45865-05	.00000

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TABLE XXXVIII (Continued)

41	205.0[illegible]	.0[illegible]	.0[illegible]	.10[illegible]+01	.00000	.45865-05	.00000
42	210.0[illegible]	.0[illegible]	.0[illegible]	.10[illegible]+01	.00000	.45865-05	.00000
43	215.0[illegible]	.0[illegible]	.0[illegible]	.10[illegible]+01	.00000	.45865-05	.00000
4[illegible]	220.0[illegible]	[illegible]	.0[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
45	2[illegible].0[illegible]	[illegible]	.0[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
46	230.0[illegible]	.0[illegible]	.0[illegible]	.10[illegible]+01	.0[illegible]	.45865-05	.00000
47	235.0[illegible]	.0[illegible]	[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
48	240.0[illegible]	[illegible]	[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
49	245.0[illegible]	[illegible]	[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
50	250.0[illegible]	[illegible]	[illegible]	.10[illegible]+01	.0[illegible]	.45865-05	.00000
51	255.00[illegible]	[illegible]	[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
52	260.0[illegible]	[illegible]	[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
53	265.0[illegible]	[illegible]	[illegible]	.10[illegible]+01	.0[illegible]	.45865-05	.00000
54	270.0[illegible]	[illegible]	[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
[illegible]	275.0[illegible]	[illegible]	.0[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
56	280.0[illegible]	[illegible]	[illegible]	.10[illegible]+01	.00000	.45865-05	.00000
57	285.0	[illegible]	[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
58	290.0[illegible]	[illegible]	[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000
59	295.0[illegible]	[illegible]	[illegible]	.10[illegible]+01	.00[illegible]	.45865-05	.00000

ASYMPTOTIC RELIABILITY INDEX IS [illegible] FAILURE PROB. = .4586452-05

UPDATED [illegible] AFTER [illegible] 1 TESTED TO PASS SAME LOAD

TEST [illegible] 1
TEST NO. 1, [illegible] TEST LOAD = 150.000

[illegible] TEST LOAD PROB.
1 150.0[illegible] .54[illegible]

REVISED [illegible] VAR = .058

TABLE XXXVIII(CONTINUED

I	K	PXL	PXS	PKS	DELPF	PF	PSM
1	5.[illegible]	.1[illegible]+01	.[illegible]	.93667-11	.93667-11	.93667-11	.00[illegible]
2	10.[illegible]	.1[illegible]+01	.122[illegible]-10	.21589-10	.12222-10	.2158[illegible]-10	.00[illegible]
3	15.[illegible]	.10[illegible]+01	.28201-10	.49790-10	.28201-10	.49789-10	.00[illegible]
4	2[illegible]	.1[illegible]+01	.65113-10	.11490-09	.65113-10	.11490-09	.00[illegible]
5	25.[illegible]	.1[illegible]+01	.150[illegible]-09	.26534-09	.15044-09	.26534-09	.00[illegible]
6	3[illegible]	.1[illegible]+01	.34781-09	.61315-09	.34781-09	.61315-09	.0[illegible]
7	3[illegible]	.1[illegible]+01	.[illegible]-09	.14178-08	.60468-09	.14178-08	.0[illegible]
8	4[illegible]	.1[illegible]+01	.1862[illegible]-08	.32805-08	.18628-08	.32805-08	.00[illegible]00
9	4[illegible]	.1[illegible]+01	.431[illegible]-08	.75957-08	.43152-08	.75957-08	.00[illegible]
10	5[illegible]	.1[illegible]+01	.1[illegible]-07	.1759[illegible]-07	.10[illegible]3-07	.1759[illegible]-07	.0[illegible]
11	5[illegible]	.1[illegible]+01	.2[illegible]-07	.40803-07	.23298-07	.40803-07	.0[illegible]
12	6[illegible]	.1[illegible]+01	.53[illegible]-07	.946[illegible]8-07	.53864-07	.946[illegible]8-07	.0[illegible]
13	6[illegible]	.1[illegible]+01	.125[illegible]-06	.2197[illegible]-06	.12512-06	.21979-06	.0[illegible]
14	7[illegible]	.[illegible]	.27[illegible]-06	.51[illegible]	.27358-06	.49317-06	.0[illegible]
15	7[illegible]	.4[illegible]	.[illegible]-06	.1193[illegible]-05	.2931[illegible]-06	.78629-06	.0[illegible]
16	80.	.1[illegible]	.1[illegible]-05	.27785-05	.16851-06	.95481-06	.0[illegible]
17	8[illegible]	.2[illegible]	.3[illegible]-05	.64578-05	.82455-07	.10373-05	.0[illegible]
18	9[illegible]	.[illegible]	.[illegible]-05	.14[illegible]-04	.39948-07	.10763-05	.0[illegible]
19	9[illegible]	.[illegible]	.1[illegible]-04	.3[illegible]-04	.18361-07	.10947-05	.0[illegible]
20	1[illegible]	.[illegible]	.[illegible]-04	.8[illegible]-04	.86383-08	.1103[illegible]-05	.0[illegible]
21	1[illegible]	.[illegible]	.1[illegible]-03	.19[illegible]-03	.40578-08	.11074-05	.0[illegible]
22	1[illegible]	.[illegible]	.[illegible]-03	.[illegible]-03	.19197-08	.11093-05	.0[illegible]
23	1[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]310-09	.11102-05	.0[illegible]
24	1[illegible]	.[illegible]	.1[illegible]	.[illegible]	.42[illegible]-09	.11106-05	.0[illegible]
25	1[illegible]	.[illegible]	.[illegible]	.[illegible]	.1983[illegible]	.11108-05	.0[illegible]
26	1[illegible]	.[illegible]	.[illegible]	.1328[illegible]-01	.92757-10	.11109-05	.0[illegible]00
27	1[illegible]	.[illegible]	.[illegible]	.3[illegible]-01	.42866-10	.11109-05	.40[illegible]78-05
28	1[illegible]	.[illegible]	.[illegible]	.6[illegible]	.19218-10	.11109-05	.4[illegible]102-02
29	1[illegible]	.[illegible]	.8[illegible]	.14938+[illegible]	.84693-11	.11110-05	.7659[illegible]-01
30	1[illegible]	.[illegible]	.[illegible]	.2[illegible]	.29717-11	.11110-05	.28361+0[illegible]
31	1[illegible]	.[illegible]	.[illegible]	.[illegible]	.87793-12	.11110-05	.41783+0[illegible]
32	1[illegible]	.[illegible]	.[illegible]	.7[illegible]	.190[illegible]-12	.11110-05	.20[illegible]

TABLE XXXVIII (Concluded)

33	165.000	.16471-12	.16571+00	.91120+00	.27459-13	.11110-05	.14870-01
34	170.000	.00000	.71447-01	.98265+00	.00000	.11110-05	.24584-04
35	175.000	.00000	.15897-01	.99855+00	.00000	.11110-05	.00000
36	180.000	.00000	.14059-02	.99995+00	.00000	.11110-05	.00000
37	185.000	.00000	.47825-04	.10000+01	.00000	.11110-05	.00000
38	190.000	.00000	.16219-06	.10000+01	.00000	.11110-05	.00000
39	195.000	.00000	.25425-09	.10000+01	.00000	.11110-05	.00000
40	200.000	.00000	.61602-15	.10000+01	.00000	.11110-05	.00000
41	205.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
42	210.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
43	215.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
44	220.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
45	225.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
46	230.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
47	235.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
48	240.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
49	245.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
50	250.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
51	255.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
52	260.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
53	265.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
54	270.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
55	275.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
56	280.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
57	285.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
58	290.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
59	295.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000

ASYMPTOTIC RELIABILITY INDEX IS .99989 FAILURE PROB. = .1110961-05

TABLE XXXVIII (Concluded)

33	165.000	.16471-12	.16571+00	.91120+00	.27459-13	.11110-05	.14870-01
34	170.000	.00000	.71447-01	.98265+00	.00000	.11110-05	.24584-04
35	175.000	.00000	.15897-01	.99855+00	.00000	.11110-05	.00000
36	180.000	.00000	.14059-02	.99995+00	.00000	.11110-05	.00000
37	185.000	.00000	.47825-04	.10000+01	.00000	.11110-05	.00000
38	190.000	.00000	.16219-06	.10000+01	.00000	.11110-05	.00000
39	195.000	.00000	.25425-09	.10000+01	.00000	.11110-05	.00000
40	200.000	.00000	.61602-15	.10000+01	.00000	.11110-05	.00000
41	205.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
42	210.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
43	215.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
44	220.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
45	225.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
46	230.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
47	235.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
48	240.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
49	245.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
50	250.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
51	255.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
52	260.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
53	265.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
54	270.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
55	275.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
56	280.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
57	285.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
58	290.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000
59	295.000	.00000	.00000	.10000+01	.00000	.11110-05	.00000

ASYMPTOTIC RELIABILITY INDEX IS .9[illegible]89 FAILURE PROB. = .1110961-05

TABLE XXXIX

STANDARD CASE, SHORT OUTPUT

```
CASE   3
STANDARD DATA, SHORT OUTPUT

LOAD DATA
UNFLD =   100.000, FS =1.500, FACLD =   150.000, MS = .000, PDSNLD =   150.000
MEAN MAX. LOAD =    80.016, VAR =  .053

INTENDED STRENGTH     AMSTR =   170.152, STS =     8.664, VARS =  .051
     BASIC (MATERIAL) MEAN STRENGTH =   150.000 VAR =  .051

INTENDED FAILURE PROB., NO DISCREPANCY, NO TEST
ASYMPTOTIC RELIABILITY INDEX IS   .9999997     FAILURE PROB. =   .3000925-06

PREDICTED FAILURE PROB., WITH PROBABLE DISCREPANCY, NO TEST
     REVISED MEAN STRENGTH =   152.500, VAR =  .071
ASYMPTOTIC RELIABILITY INDEX IS   .9999954     FAILURE PROB. =   .4586452-05

UPDATED FAILURE PROB. AFTER      1 TEST(S) TO PASS SAME LOAD

TEST SERIES  1
TEST NO.  1, TEST FACTOR =1.500, TEST LOAD =   150.000
     REVISED MEAN STRENGTH =   156.412, VAR =  .058
ASYMPTOTIC RELIABILITY INDEX IS   .99  89     FAILURE PROB. =   .1110961-05
```

CASE NO. 1 STANDARD DATA FULL OUTPUT
INTENDED FAILURE PROB.. NO DISCREPANCY, NO TEST

INTENDED STRENGTH = 170.152
BASIC MEAN STRENGTH = 150.000

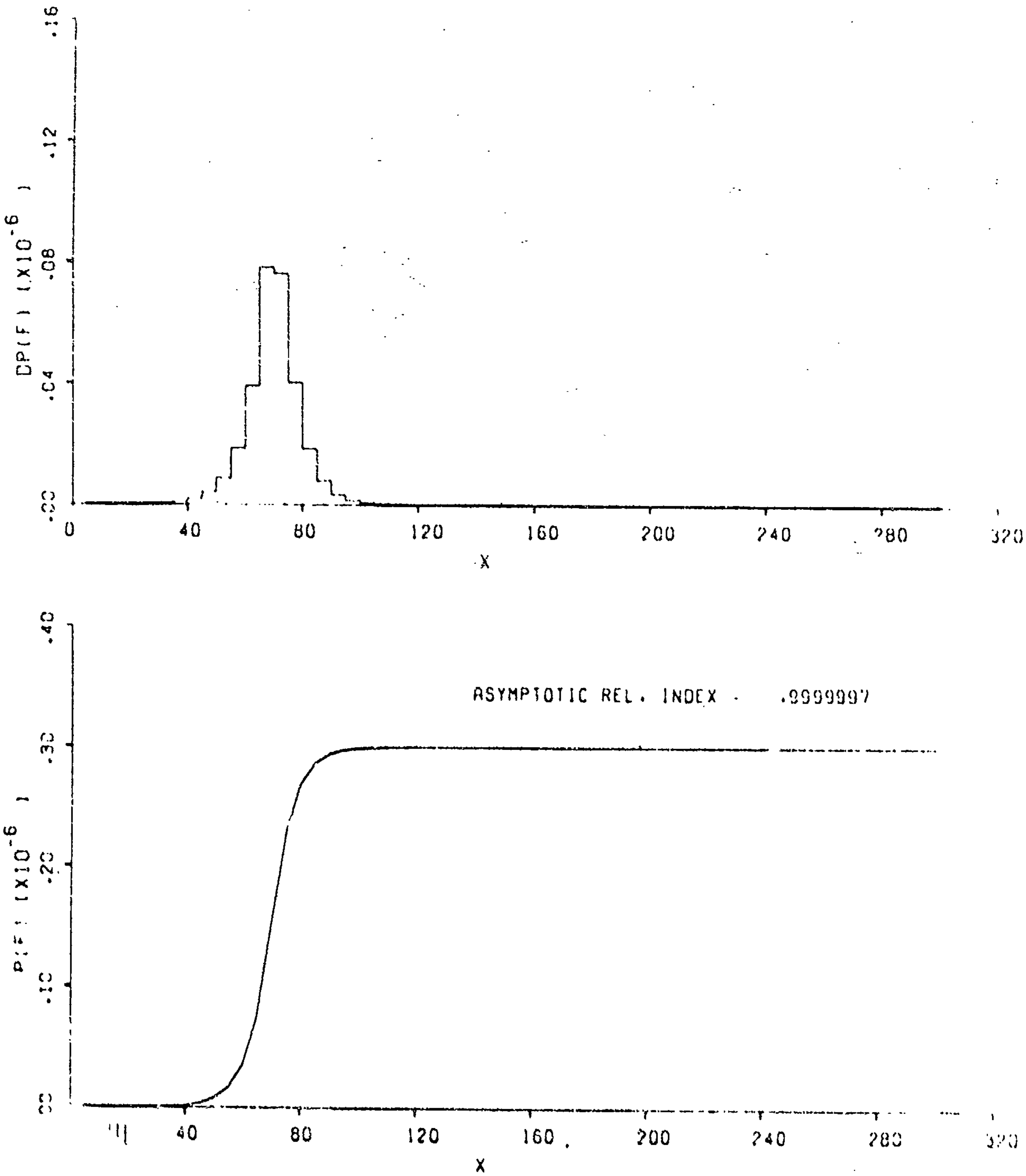
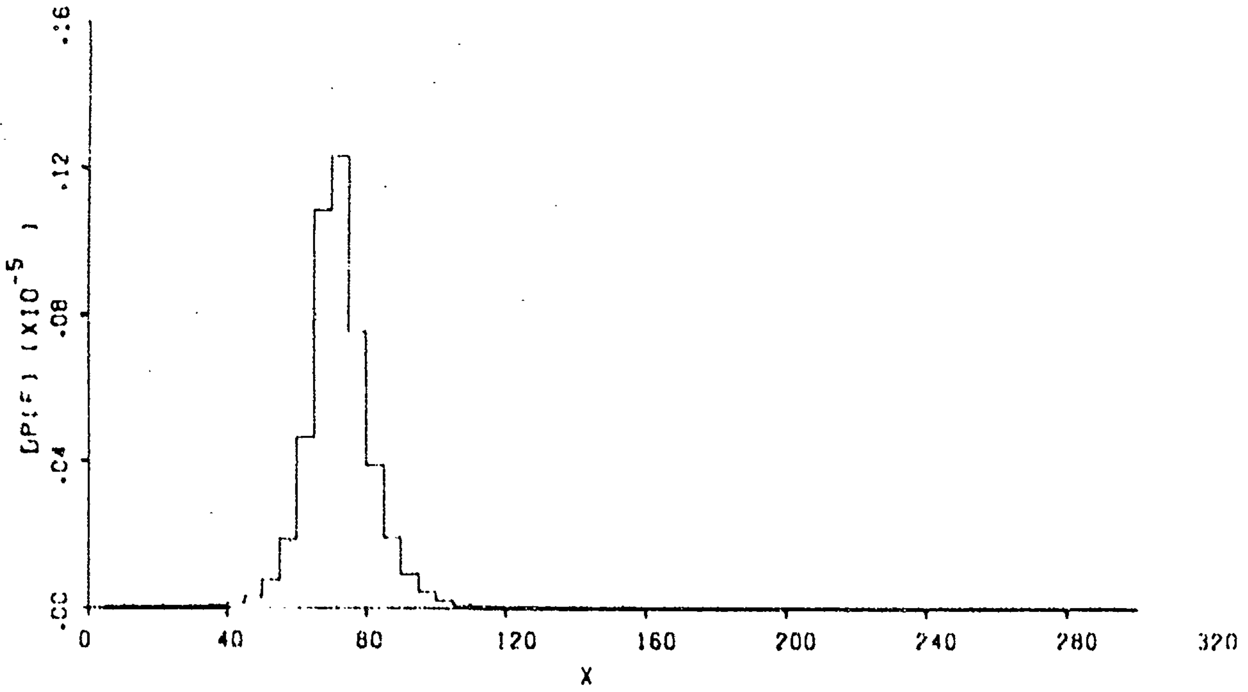


FIGURE 99 CALCOMP PLOTS OF STANDARD CASE (FULL OUTPUT) (a) Intended Reliability

CASE NO. 1 STANDARD DATA FULL OUTPUT
PREDICTED FAILURE PROB. WITH PROB. DISCREPANCY. NO TEST

REVISED MEAN STRENGTH = 152.500
VAR = .071



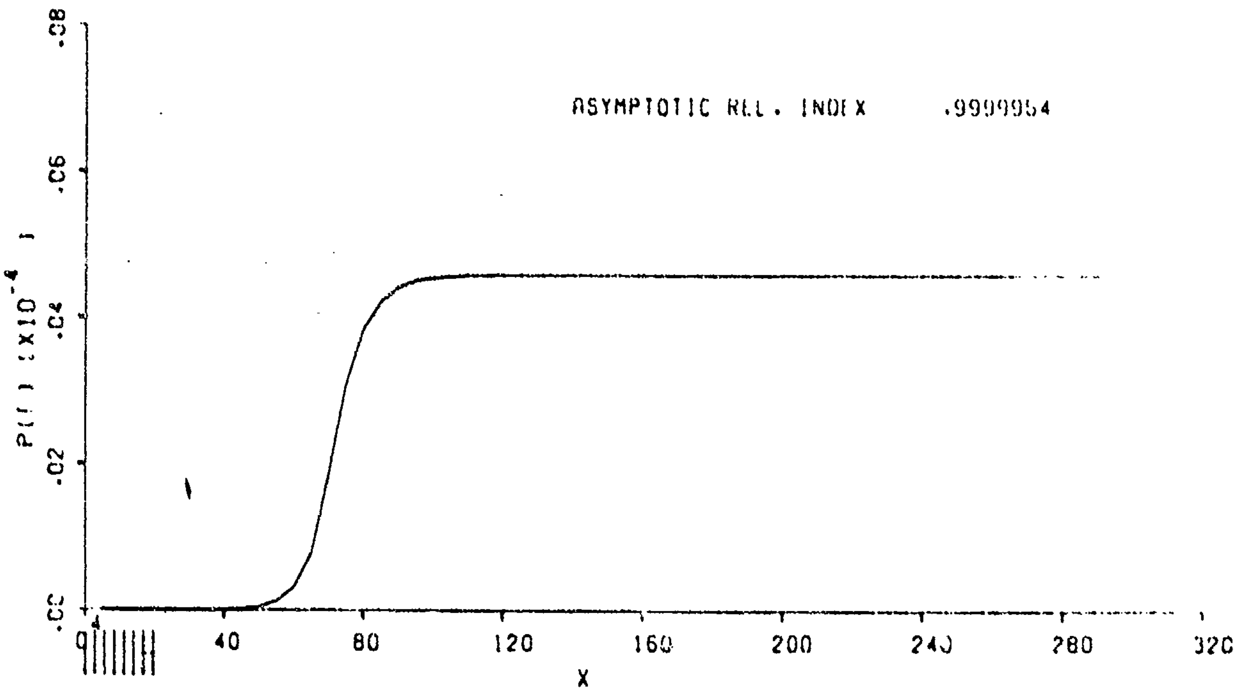
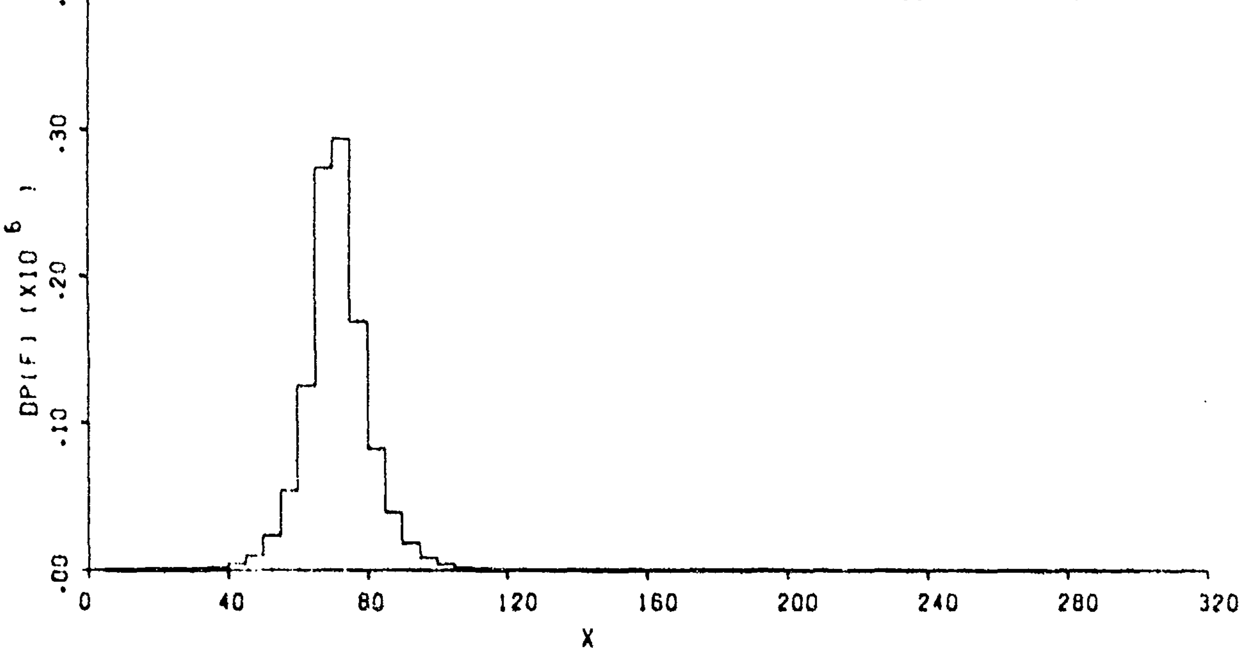


FIGURE 99 (CONTINUED) (b) With probable discrepancy, no test

CASE NO. 1 STANDARD DATA FULL OUTPUT
UPDATED FAILURE PROB. AFTER 1 TESTS TO PASS SAME LOAD
TEST NO. 1 TEST FACTOR 1.500 TEST LOAD 150.000
REVISED MEAN STRENGTH = 156.4[illegible]2
VAR = .058
PROB. OF SURVIVING NEXT TESTS

TEST	LOAD	PROB.
1	150.000	.544



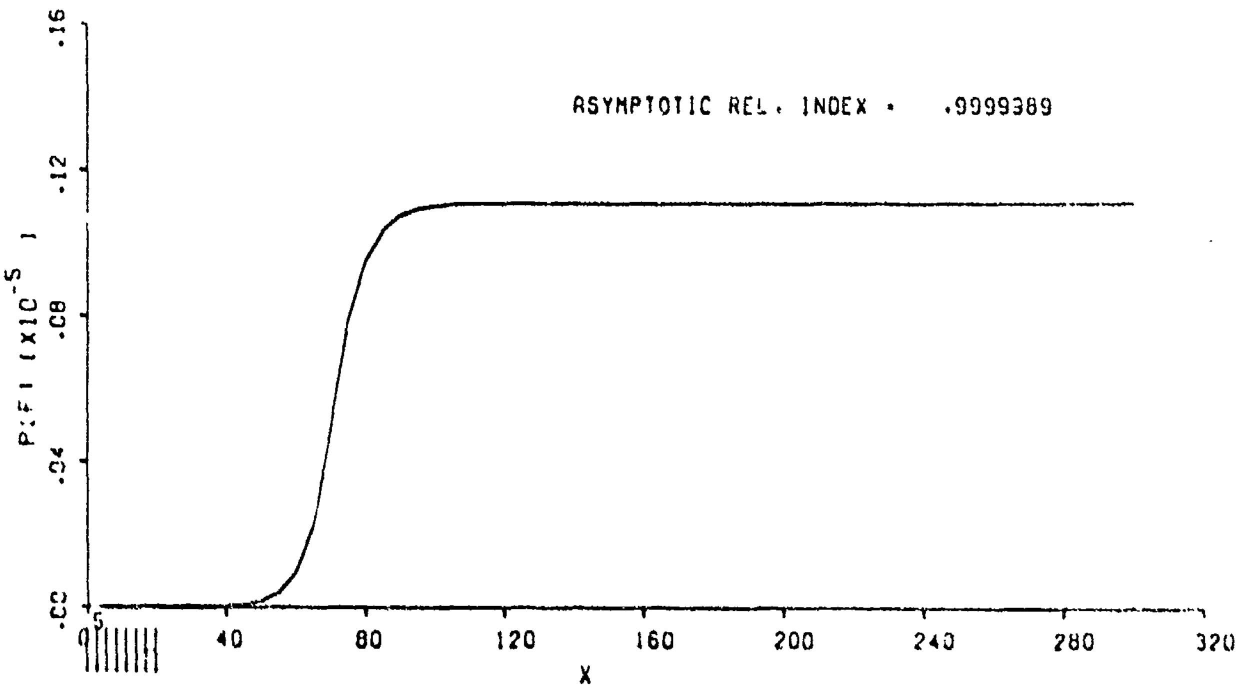


FIGURE 99 (CONCLUDED) (c) After one test

TABLE XL
OUTPUT OF C-141 EXAMPLE 1
(a) Input and Loads

```
CASE    1
PSD GUST LOADS FOR COMPARISON WITH BOUTON PROGRAM

DATA
```

1	2	3	4	5	6	7	8	9	10
UNFLD	FS	DX	RNB	RKML	LBARA	LVARA	LSUMB	LBARB	LVARB
100.000	1.50	5.00	100.	3.	80.000	.050	.000	80.000	.050

11	12	13	14	15	16	17	18	19	20
SALL	MS	DSMLD	RKS	RKMS	SBARA	SVARA	SSUMB	SBARB	SVARB
2.326	.00	.000	1.	1.	102.600	.040	.250	92.000	.040

21	22	23	24	25	26	27	28	29	30
FBARA	FVARA	FSUMB	FBARB	FVARB	RKE	PF1	PPU1	PF2	PPU2
100.000	.012	-.050	97.500	.050	4.	1.050	.050	.050	.950

31	32	33	34	35	36	37	38	39	40	41	42
RKT	RMT	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
1.	3.	1.500	.000	.000	.000	.000	.000	.000	.000	.000	.000

```
LOAD DATA
UNFLD =   100.000, FS =1.500, FACLD =   150.000, MS = .000, PDSMLD =   150.000
LOADS SPECTRUM INPUT FROM XMIN =     65.000
```

TABLE XL (CONTINUED) (b) Intended Reliability

INTENDED STRENGTH ANSTR = 176.799, STS = 11.5;8, VARS = .065

BASIC (MATERIAL) MEAN STRENGTH = 99.96, VAR = .063

RESULTANT BASIC MEAN STRENGTH = 105.028, VAR = .065

INTENDED FAILURE PROB., NO DISCREPANCY, NO TEST

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.27680-08	.11718-08	.11718-08	.11718-08	.00000
14	70.000	.54400+00	.63428-08	.20615-08	.34505-08	.46223-08	.00000
15	75.000	.22400+00	.14679-07	.53521-08	.32882-08	.79105-08	.00000
16	80.000	.96400-01	.34236-07	.13934-07	.33004-08	.11211-07	.00000
17	85.000	.42700-01	.60451-07	.36346-07	.34352-08	.14646-07	.00000
18	90.000	.19300-01	.19054-06	.94974-07	.36774-08	.18324-07	.00000
19	95.000	.8[illegible]-02	.45483-06	.24924-06	.40402-08	.22364-07	.00000
20	100.000	.41220-02	.10707-05	.65440-06	.44958-08	.26860-07	.00000
21	105.000	.19300-02	.26261-05	.17231-05	.50722-08	.31932-07	.00000
22	110.000	.90500-03	.63404-05	.45381-05	.57381-08	.37670-07	.00000
23	115.000	.42700-03	.15322-04	.11970-04	.65423-08	.44212-07	.00000
24	120.000	.20200-03	.37080-04	.31661-04	.74902-08	.51702-07	.00000
25	125.000	.95600-04	.89747-04	.83914-04	.85798-08	.60282-07	.00000
26	130.000	.45300-04	.21876-03	.22275-03	.99098-08	.70192-07	.00000
27	135.000	.21500-04	.53484-03	.59194-03	.11499-07	.81691-07	.00000
28	140.000	.10200-04	.13114-02	.15736-02	.13376-07	.95067-07	.00000
29	145.000	.48700-05	.32241-02	.41755-02	.15704-07	.11077-06	.00000
30	150.000	.23200-05	.79175-02	.11000-01	.18369-07	.12914-06	.00000
31	155.000	.11000-05	.19114-01	.28460-01	.21027-07	.15016-06	.00000
32	160.000	.52700-06	.43172-01	.69407-01	.22752-07	.17292-06	.00000
33	165.000	[illegible]	.81096-01	.14792+00	.20274-07	.19319-06	.00000
34	170.000	.11900-06	.10782+00	.25266+00	.12830-07	.20602-06	.00000
35	175.000	.56700-07	.19853+00	.35723+00	.61534-08	.21217-06	.10000+01
36	180.000	.27000-07	.13682+00	.49015+00	.36992-08	.21587-06	.00000
37	185.000	.00000	.20365+00	.69145+00	.00000	.21587-06	.00000
38	190.000	.00000	.20285+00	.89234+00	.00000	.21587-06	.00000
39	195.000	.00000	.96953-01	.98680+00	.00000	.21587-06	.00000
59	295.000	.00000	.00000	.10000+01	.00000	.21587-06	.00000

TOTAL [illegible] STRUCTURE AT LOAD OF 100.000 .26600-07

RELIABILITY INDEX AT THIS LOAD LEVEL IS 1.0000000

ASYMPTOTIC RELIABILITY INDEX IS .9799998

TABLE XL (CONTINUED) (c) With Probable Discrepancy, No Test

PREDICTED FAILURE PROB., WITH PROBABLE DISCREPANCY, NO TEST
REVISED MEAN STRENGTH = 161.993, VAR = .C82

I	X	PXL	PXS	PRS	DELPF	PF	PS_M
13	65.000	.10000+01	.12498-06	.17873-06	.17873-06	.17873-06	.15052-06
14	70.000	.54400+00	.31460-06	.44116-06	.17114-06	.34988-06	.34548-06
15	75.000	.22400+00	.79602-06	.10966-05	.17831-06	.52819-06	.79445-06
16	80.000	.96400-01	.20222-05	.27450-05	.19494-06	.72313-06	.18120-05
17	85.000	.42700-01	.51431-05	.69142-05	.21961-06	.94274-06	.41019-05
18	90.000	.19300-01	.13052-04	.17494-04	.25190-06	.11946-05	.95651-05
19	95.000	.88830-02	.32907-04	.44328-04	.29231-06	.14670-05	.22000-04
20	100.000	.41220-02	.82.36-04	.11203-03	.33824-06	.18252-05	.50687-04
21	105.000	.19300-02	.20143-03	.28110-03	.38876-06	.22139-05	.11674-03
22	110.000	.90500-03	.48429-03	.69628-03	.43828-06	.26522-05	.27005-03
23	115.000	.42700-03	.11336-02	.16916-02	.48405-06	.31363-05	.62423-03
24	120.000	.20200-03	.25643-02	.39999-02	.51799-06	.36543-05	.14429-02
25	125.000	.95600-04	.55521-02	.91195-02	.53078-06	.41851-05	.33273-02
26	130.000	.45300-04	.11446-01	.19835-01	.51859-06	.47036-05	.76112-02
27	135.000	.21500-04	.22042-01	.40713-01	.47389-06	.51775-05	.17033-01
28	140.000	.10200-04	.39155-01	.78167-01	.39938-06	.55769-05	.36206-01
29	145.000	.48700-05	.63513-01	.13940+00	.30731-06	.58862-05	.69803-01
30	150.000	.23200-05	.92509-01	.22913+00	.21462-06	.61008-05	.12097+00
31	155.000	.11020-05	.11885+00	.34507+00	.13074-06	.62316-05	.20063+00
32	160.000	.52700-06	.13627+00	.47831+00	.71613-07	.63034-05	.27443+00
33	165.000	.25000-06	.14618+00	.62166+00	.36545-07	.63399-05	.21313+00
34	170.000	.11900-06	.14672+00	.76608+00	.17459-07	.63574-05	.52827-01
35	175.000	.57700-07	.12397+00	.88529+00	.70291-08	.63644-05	.14351-02
36	180.000	.27000-07	.76739-01	.96359+00	.20720-08	.63665-05	.43972-06
37	185.000	.00000	.30400-01	.99318+00	.00000	.63665-05	.00000
38	190.000	.00000	.77458-02	.99943+00	.00000	.63665-05	.00000
39	195.000	.00000	.70091-03	.99999+00	.00000	.63665-05	.00000
59	295.000	.00000	.00000	.10000+01	.00000	.63665-05	.00000

TOTAL RISK OF UNDERSTRENGTH STRUCTURE AT LOAD OF 100.000 = .18252-05
RELIABILITY INDEX AT THIS LOAD LEVEL IS .9999982
ASYMPTOTIC RELIABILITY INDEX IS .9999936

TABLE XL (CONTINUED) (d) After One Test

UPDATED FAILURE PROB. AFTER 3 TEST(S) TO PASS SAME LOAD

TEST SERIES 1
TEST NO. 1, TEST FACTOR =1.500, TEST LOAD = 150.000

PROBABILITY OF SURVIVING NEXT TEST(S)

TEST	LOAD	PROB.
1	150.000	.771
2	150.000	.594
3	150.000	.958

REVISED MEAN STRENGTH = 165.057 VAR = .071

I	X	PXL	PXS	PRS	DELPF	PF	PS
13	65.000	.10000+01	.90187-08	.28860-08	.28860-08	.28660-08	.00000
14	70.000	.50000+00	.23108-07	.83632-08	.12571-07	.15457-07	.00000
15	75.000	.22400+00	.59778-07	.24452-07	.13390-07	.28847-07	.00000
16	80.000	.98400-01	.15060-06	.71820-07	.15096-07	.43943-07	.00000
17	85.000	.42700-01	.41451-06	.21203-06	.17699-07	.61643-07	.00000
18	90.000	.18300-01	.11077-05	.62920-06	.21383-07	.83026-07	.00000
19	95.000	.68830-02	.29788-05	.18736-05	.26460-07	.10949-06	.00000
20	100.000	.31220-02	.80500-05	.57020-05	.33182-07	.14267-06	.00000
21	105.000	.13310-02	.21136-04	.16826-04	.42144-07	.18481-06	.00000
22	110.000	.55900-03	.59376-04	.50759-04	.53753-07	.23857-06	.00000
23	115.000	.22700-03	.16174-03	.15370-03	.69159-07	.30772-06	.00000
24	120.000	.90200-03	.44279-03	.46677-03	.89444-07	.39717-06	.00000
25	125.000	.33660-04	.12132-02	.14172-02	.11598-06	.51315-06	.00000
26	130.000	.[illegible]-04	.33495-02	.42613-02	.15171-06	.66486-06	.00000
27	135.000	.21500-04	.89937-02	.12363-01	.19336-06	.85822-06	.56638-10
28	140.000	.10200-04	.21935-0[illegible]	.32866-01	.22374-06	.[illegible]	.18571-03
29	145.[illegible]	.42700-05	.[illegible]-01	.75913-01	.21973-06	.13017-05	.16618-01
30	150.[illegible]	.23200-05	.75[illegible]-01	.14919+00	.17629-[illegible]	.14766-05	.96603-01
31	155.000	.11000-05	.10713+00	.25328+00	.11785-06	.15958-05	.21592+00
32	[illegible]	.52700-06	.13420+00	.[illegible]+00	.7[illegible]23-07	.16662-05	.33430+00
33	[illegible]	.25000-06	.15827+00	.53926+00	.39571-07	.17061-05	.27164+00
34	[illegible]	.[illegible]	.171[illegible]+00	.7[illegible]82[illegible]	.20421-07	.1722[illegible]-05	.66522-01
35	175.[illegible]	.[illegible]	.[illegible]212+00	.[illegible]	.86253-08	.17352-05	19402-02
36	[illegible]	.[illegible]	.5[illegible]	.[illegible]	.20137-08	.1737[illegible]	.57[illegible]23-06
37	[illegible]	.[illegible]	.39177-01	.9[illegible]110+00	.00000	.1737[illegible]-05	.00000
38	[illegible]	.[illegible]	.87159-02	.99926+00	.00000	.1737[illegible]-05	.00000
39	[illegible]	.[illegible]	.[illegible]983-03	.99999+00	.00000	.17378-05	.00000
59	295.[illegible]	.[illegible]	.00000	.10000+01	.00000	.1737[illegible]-05	.00000

TOTAL [illegible] OF [illegible] STRUCTURE AT LOAD OF 100.000 = .14267-06

[illegible] LEVEL 15 .9999999

ASYMPTOTIC RELIABILITY [illegible] 15 .9999983

TABLE XL (CONTINUED) (e) After two Tests

TEST NO. 2, TEST FACTOR =1.500, TEST LOAD = 150.000

PROBABILITY OF SURVIVING NEXT TEST(S)

TEST	LOAD	PROB.
2	150.000	.951
3	150.000	.729

REVISED MEAN STRENGTH = 165.881, VAR = .070

I	X	PXL	PXS	PRS	ULLPF	FF	PSM
13	65.000	.10000+01	.82661-08	.26247-08	.26247-08	.26247-08	.00000
14	70.000	[illegible]	.20976-07	.75192-08	.11412-07	.14837-07	.00000
15	75.000	.22400+00	.53723-07	.21748-07	.12034-07	.26071-07	.00000
16	80.000	.96460-01	.13925-06	.63155-07	.13423-07	.39494-07	.00000
17	85.000	.42700-01	.36457-06	.18426-06	.15565-07	.55059-07	.00000
18	90.000	.19300-01	.96342-06	.54621-06	.18594-07	.73653-07	.00000
19	95.000	.88830-02	.25611-05	.15883-05	.22750-07	.96403-07	.00000
20	100.000	.54225-02	.68417-05	.46866-05	.28261-07	.12466-06	.00000
21	105.000	.19300-02	.16390-04	.13884-04	.35396-07	.16000-06	.00000
22	110.000	.905[illegible]-03	.49263-04	.41241-04	.44601-07	.20460-06	.00000
23	115.000	.42700-03	.13271-03	.12325-03	.56665-07	.26127-06	.00000
24	120.000	.262[illegible]-03	.35507-03	.36F91-03	.72339-07	.33366-06	.00000
25	125.000	.95602-04	.96827-03	.11053-02	.9256[illegible]-07	.42615-06	.00000
26	130.000	[illegible]-04	.2645[illegible]-02	.32956-02	.11965-06	.54461-06	.00000
27	135.000	.21500-04	.71976-02	.96220-02	.15367-06	.69969-06	.00000
28	140.000	.1026[illegible]	.1[illegible]-01	.26443-01	.16531-06	.88500-06	.82807-06
29	145.000	.49760-05	.39917-01	.64376-01	.19439-06	.10794-05	.35258-02
30	150.000	.23210-05	.7996[illegible]-01	.13249+00	.16418-06	.12940-05	.59122-01
31	155.000	.11000-05	.1920[illegible]	.23169+00	.11220-06	.13562-05	.20220+00
32	160.000	.57[illegible]	.12[illegible]	.35641+00	.66616-07	.14228-05	.31455+00
33	165.000	.250[illegible]	.1[illegible]	.50F80+00	.38872-07	.14627-05	.30126+00
34	170.000	[illegible]	.17[illegible]	.68276+00	.21025-07	.14837-05	.77336-01
35	175.000	.56700-07	.162[illegible]	.84347+00	.92351-08	.14929-05	.22055-02
36	180.000	[illegible]	[illegible]	.99[illegible]+00	.2[illegible]-08	.14956-05	.65773-06
37	185.000	[illegible]	.43[illegible]-01	.99[illegible]+00	.00000	.14958-05	.00000
38	190.000	[illegible]	.[illegible]-02	.99917+00	.00000	.14958-05	.00000
39	195.000	[illegible]	.10277-02	.99995+00	.00000	.14958-05	.00000
59	295.000	[illegible]	[illegible]	.100[illegible]+01	.00000	.14958-05	.00000

TOTAL RISK OF [illegible] STRUCTURE AT LOAD OF 100.000 = .12460-06

[illegible] IS .999999

[illegible] RELIABILITY INDEX IS .999995

TABLE XL (CONCLUDED) (f) After Three Tests

TEST NO. 3, TEST FACTOR =1.500, TEST LOAD = 150.000

PROBABILITY OF SURVIVING NEXT TEST(S)

TEST	LOAD	PROB.
3	150.000	.847

REVISED MEAN STRENGTH = 166.429, VAR = .069

I	X	PFL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.76357-08	.24771-08	.24771-08	.24771-08	.00000
14	70.000	.59400+00	.19771-07	.70467-08	.10756-07	.13233-07	.00000
15	75.000	.27400+00	.50338-07	.20259-07	.11775-07	.24500-07	.00000
16	80.000	.97466-01	.12967-06	.56834-07	.12500-07	.37006-07	.00000
17	85.000	.27700-01	.33727-06	.17953-06	.14401-07	.51405-07	.00000
18	90.000	.16310-01	.61563-06	.45297-06	.17093-07	.68507-07	.00000
19	95.000	.88038-02	.21391-05	.14290-05	.20771-07	.89280-07	.00000
20	100.000	.41228-02	.62074-05	.42185-05	.25518-07	.11487-06	.00000
21	[illegible]	.19350-02	.16329-04	.12391-04	.31911-07	.14677-06	.00000
22	[illegible]	.91500-03	.49113-04	.38557-04	.39572-07	.18669-06	.00000
23	[illegible]	.42710-03	.11795-03	.11823-03	.50364-07	.23705-06	.00000
24	120.000	.20200-03	.31599-03	.32137-03	.73817-07	.30087-06	.00000
25	125.000	.94400-04	.18714-03	.95524-03	.81058-07	.38193-06	.00000
26	130.000	.45300-04	.23014-02	.28310-02	.10426-06	.48619-06	.00003
27	135.000	[illegible]	.62120-02	.82667-02	.13359-06	.61978-06	.00003
28	140.000	[illegible]	.16042-01	.23016-01	.16542-06	.78336-06	.35973-08
29	[illegible]	[illegible]	[illegible]	.57626-01	.17792-06	.96130-06	.71893-03
30	[illegible]	.232[illegible]	.67521-01	.12256+00	.15645-06	.11180-05	.37499-01
31	[illegible]	[illegible]	[illegible]	.21863[illegible]	.10191-06	.12269-05	.16417+00
32	[illegible]	[illegible]	.17431+00	.33956+00	.75523-07	.12424-05	.36532+00
33	[illegible]	[illegible]	[illegible]	[illegible]	.31[illegible]	.13304-05	[illegible]
34	[illegible]	[illegible]	[illegible]	.76394[illegible]	.21227-07	.13517-05	.84695-01
35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1361[illegible]	.24384-02
36	[illegible]	[illegible]	[illegible]	.9832[illegible]	[illegible]	.1364[illegible]	.72747-06
37	[illegible]	[illegible]	[illegible]	.9991[illegible]	.00000	.13644-05	.00000
38	[illegible]	[illegible]	[illegible]	[illegible]	.00000	.13644-05	.00000
39	[illegible]	[illegible]	[illegible]	[illegible]	.00000	.13644-05	.00000
59	[illegible]	[illegible]	[illegible]	.10000+01	.00000	.13644-05	.00000

[illegible] .11487-06

[illegible] .9999999

[illegible]

TABLE XLI
OUTPUT OF C-141 EXAMPLE 4
(a) Input and Loads

CASE 4

~~3D MOST LOADS FOR COMPARISON WITH BOUTON PROGRAM~~

DATA

1	2	3	4	5	6	7	8	9	10
UNFLD	FS	DJ	RUB	RKBL	LBARA	LVARA	LSURA	LBARB	LVARB
100.[illegible]	1.5[illegible]	5.00	100.	3.	80.000	.050	.000	80.000	.050

11	12	13	14	15	16	17	18	19	20
SALL	DS	[illegible]	RES	EKES	SBARA	SVARA	SSURB	SBARB	SVARB
2.37[illegible]	.[illegible]	1[illegible]	1.	1.	102.600	.040	.250	92.000	.040

21	22	23	24	25	26	27	28	29	30
FBARA	FVARA	FSURA	FBARB	FVARB	TKF	PT1	PPUT	PT2	PPU2
100.[illegible]	.017	-.[illegible]	97.500	.050	1.	1.000	1.185	.010	.333

31	32	33	34	35	36	37	38	39	40	41	42
[illegible]	[illegible]	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
1.	3.	1.[illegible]	.000	.000	.000	.000	.000	.000	.000	.000	.000

LOAD DATA

UNFLD = 100.[illegible], FS =1.5[illegible], FACLD = 150.000, KS = .000, POSNLD = 150.000

LOADS SPECIFIED INPUT FROM AMIF = 65.000

TABLE XLI (CONTINUED) (b) Probable Discrepancy, No Test

PREDICTED FAILURE PROB., WITH PROBABLE DISCREPANCY, NO TEST
REVISED MEAN STRENGTH = 144.679, VAR = .222

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.61950-02	.23053-01	.23053-01	.23053-01	.72633-02
14	70.000	.54400+00	.76339-02	.30533-01	.41529-02	.27206-01	.88237-02
15	75.000	.22400+00	.92569-02	.39588-01	.20735-02	.29280-01	.10577-01
16	80.000	.96400-01	.11082-01	.50415-01	.10683-02	.30348-01	.12530-01
17	85.000	.42700-01	.13125-01	.63226-01	.56050-03	.30709-01	.14673-01
18	90.000	.19300-01	.15401-01	.78246-01	.29724-03	.31206-01	.17074-01
19	95.000	.88830-02	.17916-01	.95711-01	.15915-03	.31365-01	.19679-01
20	100.000	.41220-02	.20679-01	.11587+00	.85230-04	.31450-01	.22518-01
21	105.000	.19300-02	.23691-01	.13896+00	.45724-04	.31496-01	.25597-01
22	110.000	.90500-03	.26953-01	.16525+00	.24392-04	.31520-01	.28925-01
23	115.000	.42700-03	.30461-01	.19498+00	.13007-04	.31533-01	.32508-01
24	120.000	.20200-03	.34214-01	.22842+00	.69113-05	.31540-01	.36354-01
25	125.000	.95600-04	.38212-01	.26581+00	.36531-05	.31544-01	.40[illegible]0-01
26	130.000	.45300-04	.42585-01	.30743+00	.19291-05	.31546-01	.44863-01
27	135.000	.21[illegible]00-0[illegible]	.47250-01	.35355+00	.10159-05	.31547-01	.49539-01
28	140.000	.10200-04	.52178-01	.40441+00	.53222-06	.31547-01	.54507-01
29	145.000	.48700-05	.57311-01	.46024+00	.27710-06	.31548-01	.59771-01
30	150.000	.23200-05	.62499-01	.52110+00	.14500-06	.31548-01	.65340-01
31	155.000	.11000-05	.67382-01	.58686+00	.74120-07	.31548-01	.71219-01
32	160.000	.52700-06	.71147-01	.65638+00	.37494-07	.31548-01	.77416-01
33	165.000	.25000-05	.72279-01	.72707+00	.18070-07	.31548-01	.83935-01
34	170.000	.11900-06	.69219-01	.79481+00	.82370-08	.31548-01	.90784-01
35	175.000	.55700-07	.63047-01	.85651+00	.35749-08	.31548-01	.97969-01
36	180.000	.27000-07	.56396-01	.91189+00	.15227-08	.31548-01	.50931-02
37	185.000	.00000	.45676-01	.95780+00	.00000	.31548-01	.00000
38	190.000	.00000	.29870-01	.98711+00	.00000	.31548-01	.00000
39	195.000	.00000	.11636-01	.99832+00	.00000	.31548-01	.00000
40	200.000	.00000	.18399-02	.99994+00	.00000	.31548-01	.00000
41	205.000	.00000	.00000	.10000+01	.00000	.31548-01	.00000

TOTAL RISK OF UNDERSTRENGTH STRUCTURE AT LOAD OF 100.000 = .31450-01
RELIABILITY INDEX AT THIS LOAD LEVEL IS .9685497
ASYMPTOTIC RELIABILITY INDEX IS .9684520

TABLE XLI (CONTINUED) (c) After One Test

UPDATED FAILURE PROB. AFTER 3 TEST(S) TO PASS SAME LOAD

TEST SERIES 1
TEST NO. 1, TEST FACTOR =1.500, TEST LOAD = 150.000

PROBABILITY OF SURVIVING NEXT TEST(S)

TEST	LOAD	PROB.
1	150.000	.479
2	150.000	.229
3	150.000	.110

REVISED MEAN STRENGTH = 169.716, VAR = .080

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.73039-08	.24186-08	.24186-08	.24186-08	.00000
14	70.000	.54400+00	.18587-07	.66860-08	.10111-07	.12530-07	.00000
15	75.000	.22400+00	.47863-07	.19501-07	.10721-07	.23251-07	.00000
16	80.000	.96400-01	.12497-06	.57208-07	.12047-07	.35298-07	.00000
17	85.000	.42700-01	.33021-06	.16889-06	.14100-07	.49398-07	.00000
18	90.000	.19300-01	.88223-06	.50197-06	.17027-07	.66425-07	.00000
19	95.000	.38830-02	.23747-05	.14992-05	.21094-07	.87519-07	.00000
20	100.000	.41220-02	.64326-05	.45021-05	.26515-07	.11403-06	.00000
21	105.000	.19300-02	.17513-04	.13601-04	.33801-07	.14784-06	.00000
22	110.000	.90500-03	.47864-04	.41313-04	.43317-07	.19115-06	.00000
23	115.000	.42700-03	.13127-03	.12609-03	.56060-07	.24721-06	.00000
24	120.000	.20200-03	.36144-03	.38617-03	.73011-07	.32022-06	.00000
25	125.000	.95600-04	.99761-03	.11815-02	.95372-07	.41559-06	.00000
26	130.000	.45300-04	.27652-02	.35635-02	.12526-06	.54086-06	.00000
27	135.000	.21500-04	.73357-02	.10226-01	.15772-06	.69 58-06	.27731-09
28	140.000	.10200-04	.17069-01	.26205-01	.17410-06	.87268-06	.47067-03
29	145.000	.48700-05	.32792-01	.57381-01	.15970-06	.10324-05	.24244-01
30	150.000	.23200-05	.53497-01	.10866+00	.12411-06	.11565-05	.82439-01
31	155.000	.11000-05	.77965-01	.18555+00	.87412-07	.12439-05	.12704+00
32	160.000	.52700-06	.10887+00	.29157+00	.57376-07	.13013-05	.15976+00
33	165.000	.25000-06	.13206+00	.42069+00	.33016-07	.13343-05	.16010+00
34	170.000	.11900-06	.13935+00	.55709+00	.16582-07	.13509-05	.19624+00
35	175.000	.56700-07	.13310+00	.68745+00	.75465-08	.13584-05	.21547+00
36	180.000	.27000-07	.12183+00	.80705+00	.32695-08	.13617-05	.11236-01
37	185.000	.00000	.10193+00	.90739+00	.00000	.13617-05	.00000
38	190.000	.00000	.65535-01	.97164+00	.00000	.13617-05	.00000
39	195.000	.00000	.25583-01	.99630+00	.00000	.13617-05	.00000
40	200.000	.00000	.40499-02	.99987+00	.00000	.13617-05	.00000
59	295.000	.00000	.00000	.10000+01	.00000	.13617-05	.00000

TOTAL RISK OF UNDERSTRENGTH STRUCTURE AT LOAD OF 100.000 = .11403-06

RELIABILITY INDEX AT THIS LOAD LEVEL IS .9999999

ASYMPTOTIC RELIABILITY INDEX IS .9999986

TABLE XLI (CONTINUED) (d) After Two Tests

TEST NO. 2, TEST FACTOR = 1.500, TEST LOAD = 150.000

PROBABILITY OF SURVIVING NEXT TEST(S)

TEST	LOAD	PROB.
2	150.000	.871
3	150.000	.794

REVISED MEAN STRENGTH = 170.992, VAR = .077

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.63157-08	.20886-08	.20886-08	.20866-08	.00000
14	70.000	.54400+00	.15806-07	.55906-08	.85985-08	.10687-07	.00000
15	75.000	.22400+00	.39997-07	.16005-07	.89594-08	.19646-07	.00000
16	80.000	.96400-01	.10252-06	.46043-07	.98831-08	.29530-07	.00000
17	85.000	.42700-01	.26581-06	.13322-06	.11350-07	.40880-07	.00000
18	90.000	.19300-01	.69664-06	.38785-06	.13445-07	.54325-07	.00000
19	95.000	.88630-02	.18394-05	.11341-05	.16339-07	.70664-07	.00000
20	100.000	.41220-02	.48867-05	.33325-05	.20143-07	.90807-07	.00000
21	105.000	.19300-02	.13046-04	.98454-05	.25179-07	.11599-06	.00000
22	110.000	.90500-03	.34951-04	.29231-04	.31631-07	.14762-06	.00000
23	115.000	.42700-03	.93937-04	.87200-04	.40111-07	.18773-06	.00000
24	120.000	.20200-03	.25327-03	.26113-03	.51160-07	.23889-06	.00000
25	125.000	.95600-04	.68486-03	.78305-03	.65475-07	.30436-06	.00000
26	130.000	.45300-04	.18707-02	.23344-02	.84741-07	.38910-06	.00000
27	135.000	.21500-04	.50211-02	.67756-02	.10795-06	.49706-06	.00000
28	140.000	.10200-04	.12475-01	.18281-01	.12725-06	.62431-06	.20410-05
29	145.000	.48700-05	.26420-01	.43218-01	.12866-06	.75297-06	.49385-02
30	150.000	.23200-05	.46390-01	.87522-01	.10763-06	.86060-06	.52235-01
31	155.000	.11000-05	.71179-01	.15618+00	.78297-07	.93889-06	.11741+00
32	160.000	.52700-06	.10066+00	.25376+00	.53047-07	.99194-06	.16351+00
33	165.000	.25000-06	.12659+00	.37952+00	.32147-07	.10241-05	.19407+00
34	170.000	.11700-06	.14287+00	.51934+00	.17002-07	.10411-05	.21740+00
35	175.000	.56700-07	.14149+00	.65794+00	.80226-08	.10491-05	.23799+00
36	180.000	.27000-07	.13225+00	.78780+00	.35707-08	.10527-05	.12448-01
37	185.000	.00000	.11179+00	.87782+00	.00000	.10527-05	.00000
38	190.000	.00000	.77211-01	.96668+00	.00000	.10527-05	.00000
39	195.000	.00000	.28248-01	.99590+00	.00000	.10527-05	.00000
40	200.000	.00000	.49769-02	.99956+00	.00000	.10527-05	.00000
59	295.000	.00000	.00000	.10000+01	.00000	.10527-05	.00000

TOTAL RISK OF UNSAFE FLIGHT STRUCTURE AT LOAD OF 100.000 = .90807-07

RELIABILITY INDEX AT THIS LOAD LEVEL IS .9999999

ASYMPTOTIC RELIABILITY INDEX IS .9999989

TABLE XLI (CONCLUDED) (e) After Three Tests

TEST NO. 3, TEST FACTOR =1.500, TEST LOAD = 150.000

PROBABILITY OF SURVIVING NEXT TEST(S)

TEST	LOAD	PROB.
3	150.000	.912

REVISED MEAN STRENGTH = 171.757, VAR = .076

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.58169-08	.19270-08	.19270-08	.19270-08	.00000
14	70.000	.54400+00	.14423-07	.59543-08	.78460-08	.97730-08	.00000
15	75.000	.22400+00	.36196-07	.14319-07	.80968-08	.17870-07	.00000
16	80.000	.96400-01	.91703-07	.40751-07	.88406-08	.26710-07	.00000
17	85.000	.42700-01	.23527-06	.11659-06	.10046-07	.36756-07	.00000
18	90.000	.17300-01	.63976-06	.33551-06	.11772-07	.48529-07	.00000
19	95.000	.68830-02	.15933-05	.96961-06	.14153-07	.62682-07	.00000
20	100.000	.41220-02	.41670-05	.28145-05	.17259-07	.79940-07	.00000
21	105.000	.17300-02	.11055-04	.82112-05	.21337-07	.10128-06	.00000
22	110.000	.90500-03	.29280-04	.24067-04	.26506-07	.12778-06	.00000
23	115.000	.42700-03	.77819-04	.70863-04	.33229-07	.16101-06	.00000
24	120.000	.20200-03	.20736-03	.20997-03	.41886-07	.20290-06	.00000
25	125.000	.95600-04	.55410-03	.62051-03	.52972-07	.25587-06	.00000
26	130.000	.45300-04	.14977-02	.18330-02	.67844-07	.32371-06	.00000
27	135.000	.21500-04	.40171-02	.53221-02	.86369-07	.41008-06	.00000
28	140.000	.10200-04	.10227-01	.14648-01	.10431-06	.51440-06	.85640-08
29	145.000	.48700-05	.22768-01	.36029-01	.11097-06	.62536-06	.97336-03
30	150.000	.23200-05	.47183-01	.76210-01	.97864-07	.72323-06	.32024-01
31	155.000	.11000-05	.66663-01	.14041+00	.73330-07	.79656-06	.10337+00
32	160.000	.52700-06	.95505-01	.23309+00	.50331-07	.84689-06	.16294+00
33	165.000	.25000-06	.12977+00	.35473+00	.31191-07	.87808-06	.20235+00
34	170.000	.11900-06	.14317+00	.49479+00	.17038-07	.89512-06	.23067+00
35	175.000	.56700-07	.14589+00	.63770+00	.82720-08	.90339-06	.25433+00
36	180.000	.27000-07	.13897+00	.77912+00	.37521-08	.90714-06	.13344-01
37	185.000	.00000	.11665+00	.89097+00	.00000	.90714-06	.00000
38	190.000	.00000	.76989-01	.96653+00	.00000	.90714-06	.00000
39	195.000	.00000	.30179-01	.99562+00	.00000	.90714-06	.00000
40	200.000	.00000	.47663-02	.99984+00	.00000	.90714-06	.00000
59	295.000	.00000	.00000	.10000+01	.00000	.90714-06	.00000

TOTAL RISK OF UNDERSTRENGTH STRUCTURE AT LOAD OF 180.000 = .79940-07

RELIABILITY INDEX AT THIS LOAD LEVEL IS .9999999

ASYMPTOTIC RELIABILITY INDEX IS .9999991

TABLE XLII
OUTPUT OF C-141 EXAMPLE 8
(a) Input and Loads

CASE 8
PSD GUST LOADS FOR COMPARISON WITH BOUTON PROGRAM

DATA

1	2	3	4	5	6	7	8	9	10
UNFLD	FS	DX	KHB	RKHB	LBARA	LVARA	LSUMB	LBARB	LVARB
100.000	1.50	5.00	100.	3.	80.000	.050	.000	80.000	.050

11	12	13	14	15	16	17	18	19	20
SALL	FS	DSMLD	RKS	RKHS	SBARA	SVARA	SSUMB	SBARB	SVARB
2.326	.60	150.000	1.	1.	102.400	.040	.250	92.000	.040

21	22	23	24	25	26	27	28	29	30
FBARA	FVARA	FSUMB	FBARB	FVARB	RKE	PF1	FPU1	PF2	FPU2
100.000	.012	-.050	97.500	.050	1.	1.000	1.185	.010	.333

31	32	33	34	35	36	37	38	39	40	41	42
RKT	RNT	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
2.	3.	1.500	1.500	1.500	.000	.000	.000	.000	.000	.000	.000

LOAD DATA
UNFLD = 100.000, FS =1.500, FACLD = 150.000, MS = .000, PDSMLD = 150.000
LOADS SELECTED INPUT FROM XMIN = 65.000

TABLE XLII (CONTINUED) (b) Probable Discrepancy, No Test

PREDICTED FAILURE PROB., WITH PROBABLE DISCREPANCY, NO TEST
REVISED MEAN STRENGTH = 144.679, VAR = .222

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.61950-02	.23053-01	.23053-01	.23053-01	.72633-02
14	70.000	.54400+00	.76339-02	.30533-01	.41529-02	.27206-01	.88237-02
15	75.000	.22400+00	.92569-02	.3958[illegible]	.20735-02	.29280-01	.10577-01
16	80.000	.96400-01	.11082-01	.50415-01	.10683-02	.30348-01	.12530-01
17	85.000	.12700-01	.13126-01	.63226-01	.56056-03	.30909-01	.14693-01
18	90.000	.19300-01	.15401-01	.78246-01	.29724-03	.31206-01	.17074-01
19	95.000	.88830-02	.17916-01	.95711-01	.15915-03	.31365-01	.19679-01
20	100.000	.41220-02	.20679-01	.11587+00	.85238-04	.31450-01	.22518-01
21	105.000	.19300-02	.23691-01	.13896+00	.45724-04	.31496-01	.25597-01
22	110.000	.90500-03	.26953-01	.16525+00	.24392-04	.31520-01	.28925-01
23	115.000	.42700-03	.30461-01	.19478+00	.13007-04	.31533-01	.32508-01
24	120.000	.20200-03	.34214-01	.22842+00	.69113-05	.31540-01	.36354-01
25	125.000	.95600-04	.38212-01	.26581+00	.36531-05	.31544-01	.40470-01
26	130.000	.45300-04	.42585-01	.30743+00	.19291-05	.31546-01	.44863-01
27	135.000	.21500-04	.47250-01	.35355+00	.10159-05	.31547-01	.49539-01
28	140.000	.10200-04	.52178-01	.40441+00	.53222-06	.31547-01	.54507-01
29	145.000	.48700-05	.57371-01	.46024+00	.27910-06	.31548-01	.59771-01
30	150.000	.23200-05	.62499-01	.52110+00	.14500-06	.31548-01	.65340-01
31	155.000	.11000-05	.67382-01	.58686+00	.74120-07	.31548-01	.71219-01
32	160.000	.[illegible]2700-06	.71147-01	.65638+00	.37494-07	.31548-01	.77416-01
33	165.000	.25000-06	.72279-01	.72707+00	.18670-07	.31548-01	.83935-01
34	170.000	.11900-06	.69219-01	.79481+00	.82370-08	.31548-01	.90784-01
35	175.000	.52700-07	.63049-01	.85654+00	.35749-08	.31548-01	.97969-01
36	180.000	.27000-07	.56396-01	.91189+00	.15227-08	.31548-01	.50931-02
37	185.000	.00000	.46676-01	.95780+00	.00000	.31548-01	.00000
38	190.000	.00000	.29870-01	.98711+00	.00000	.31548-01	.00000
39	195.000	.00000	.11636-01	.99832+00	.00000	.31548-01	.00000
40	200.000	.00000	.18399-02	.99994+00	.00000	.31548-01	.00000
59	295.000	.00000	.00000	.10000+01	.00000	.31548-01	.00000

TOTAL RISK OF UNDERSTRENGTH STRUCTURE AT LOAD OF 100.000 = .31450-01
RELIABILITY INDEX AT THIS LOAD LEVEL IS .9685497
ASYMPTOTIC RELIABILITY INDEX IS .9684520

TABLE XLII (CONTINUED) (c) After One Test

UPDATED FAILURE PROB. AFTER 3 TEST(S) TO ACTUAL FAILING LOAD

TEST NO. 1. TEST FACTOR =1.500. TEST LOAD = 150.000

PROBABILITY OF SURVIVING NEXT TEST(S)

TEST	LOAD	PROB.
1	150.000	.479
2	150.000	.229
3	150.000	.110

REVISED MEAN STRENGTH = 156.326, VAR = .075

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10100+01	.19061-07	.64480-08	.64480-08	.64480-08	.00000
14	70.000	.54400+00	.52050-07	.20043-07	.28315-07	.34763-07	.00000
15	75.000	.22400+00	.14366-06	.62634-07	.32180-07	.66943-07	.00000
16	80.000	.96400-01	.40170-06	.19667-06	.38724-07	.10567-06	.00000
17	85.000	.42700-01	.11339-05	.62008-06	.48417-07	.15408-06	.00000
18	90.000	.19300-01	.32262-05	.19644-05	.62266-07	.21635-06	.00000
19	95.000	.84800-02	.92190-05	.62414-05	.81692-07	.29824-06	.00000
20	100.000	.41?20-02	.26445-04	.19913-04	.10901-06	.40725-06	.00000
21	105.000	.19300-02	.76072-04	.63799-04	.14682-06	.55407-06	.00000
22	110.000	.90500-03	.21931-03	.20511-03	.19648-06	.75255-06	.00000
23	115.000	.42700-03	.63385-03	.66089-03	.27065-06	.10232-05	.00000
24	120.000	.20200-03	.18361-02	.21272-02	.37089-06	.13941-05	.00000
25	125.000	.95600-04	.53007-02	.67674-02	.50675-06	.19006-05	.00000
26	130.000	.45300-04	.14946-01	.20611-01	.67705-06	.25779-05	.00000
27	135.000	.21500-04	.37007-01	.55917-01	.79569-06	.33736-05	.13468-04
28	140.000	.10200-04	.70417-01	.12397+00	.71825-06	.40918-05	.36238-01
29	145.000	.48700-05	.10109+00	.22205+00	.49230-06	.45841-05	.29475+00
30	150.000	.23200-05	.13044+00	.34900+00	.30262-06	.48867-05	.33369+00
31	155.000	.11000-05	.16971+00	.51584+00	.16668-06	.50734-05	.16651+00
32	160.000	.527[illegible]0-06	.18481+00	.69829+00	.97394-07	.51708-05	.85423-01
33	165.000	.25000-06	.14566+00	.84182+00	.36415-07	.52072-05	.37917-01
34	170.000	.11900-06	.86174-01	.92626+00	.10255-07	.52175-05	.17186-01
35	175.000	.56700-07	.12653-01	.96781+00	.24164-08	.52199-05	.80762-02
36	180.000	.27000-07	.19737-01	.98696+00	.53290-09	.52204-05	.19054-03
37	185.000	.00000	.88422-02	.99552+00	.00000	.52204-05	.00000
38	190.000	.00000	.35442-02	.99893+00	.00000	.52204-05	.00000
39	195.000	.00000	.19138-02	.99989+00	.00000	.52204-05	.00000
40	200.000	.00000	.12955-03	.10000+01	.00000	.52204-05	.00000
59	295.000	.00000	.00000	.10000+01	.00000	.52204-05	.00000

TOTAL RISK OF UNDERSTRENGTH STRUCTURE AT LOAD OF 100.000 = .40725-06

RELIABILITY INDEX AT THIS LOAD LEVEL IS .9999996

ASYMPTOTIC RELIABILITY INDEX IS .9999948

TABLE XLII (CONTINUED) (d) After Two Tests

TEST NO. 2, TEST FACTOR =1.500, TEST LOAD = 150.000

PROBABILITY OF SURVIVING NEXT TEST(S)

TEST	LOAD	PROB.
2	150.000	.651
3	150.000	.424

REVISED MEAN STRENGTH = 154.256, VAR = .066

I	X	PXL	PXS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.20867-07	.70652-06	.70652-08	.70652-08	.00000
14	70.000	.54400+00	.57069-07	.22007-07	.31056-07	.38122-07	.00000
15	75.000	.22400+00	.15772-06	.68780-07	.35330-07	.73452-07	.00000
16	80.000	.96400-01	.44125-06	.21594-06	.42537-07	.11599-06	.00000
17	85.000	.42700-01	.12453-05	.68016-06	.53173-07	.16916-06	.00000
18	90.000	.19300-01	.35403-05	.21511-05	.68327-07	.23749-06	.00000
19	95.000	.88830-02	.10100-04	.68169-05	.89721-07	.32721-06	.00000
20	100.000	.41220-02	.28911-04	.21677-04	.11917-06	.44638-06	.00000
21	105.000	.19300-02	.82940-04	.69185-04	.16007-06	.60645-06	.00000
22	110.000	.90500-03	.23831-03	.22144-03	.21567-06	.82212-06	.00000
23	115.000	.42700-03	.68601-03	.71011-03	.29293-06	.11151-05	.00000
24	120.000	.20200-03	.19789-02	.22760-02	.39975-06	.15148-05	.00000
25	125.000	.95600-04	.57032-02	.72351-02	.54522-06	.20600-05	.00000
26	130.000	.45300-04	.16270-01	.22274-01	.73703-06	.27971-05	.00000
27	135.000	.21500-04	.41897-01	.62291-01	.90080-06	.36979-05	.96726-09
28	140.000	.10200-04	.82068-01	.14172+00	.83646-06	.45343-05	.63643-02
29	145.000	.42700-05	.11410+00	.25255+00	.55564-06	.50900-05	.36395+00
30	150.000	.23200-05	.13977+00	.38854+00	.32427-06	.54142-05	.45019+00
31	155.000	.11000-05	.18722+00	.57291+00	.20595-06	.56202-05	.12903+00
32	[illegible]	.527[illegible]-04	.29743+00	.77630+00	.10932-06	.57295-05	.24960-01
33	165.000	.25000-06	.14512+00	.92147+00	.36280-07	.57658-05	.45249-02
34	170.000	.11700-06	.50718-01	.98057+00	.72255-08	.57730-05	.65948-03
35	175.000	.567[illegible]0-07	.16148-01	.99591+00	.91557-09	.57739-05	.17567-03
36	[illegible]	.270[illegible]0-07	.30078-02	.99917+00	.79764-10	.57740-05	.18830-05
37	185.000	[illegible]	.73015-03	.99984+00	.00000	.57740-05	.00000
38	190.000	.00000	.15057-03	.99997+00	.00000	.57740-05	.00000
39	195.000	[illegible]	.27[illegible]3-04	.10000+01	.00000	.57740-05	.00000
59	295.000	[illegible]	.0[illegible]	.10000+01	.00000	.57740-05	.00000

TOTAL RISK OF UNDERSTRENGTH STRUCTURE AT LOAD OF 100.000 = .[illegible] 638-06

RELIABILITY INDEX AT THIS LOAD LEVEL IS .9995996

ASYMPTOTIC RELIABILITY INDEX IS .9999942

TABLE XLII (CONCLUDED) (e) After Three Tests

TEST NO. 3, TEST FACTOR = 1.500, TEST LOAD = 150.000

PROBABILITY OF SURVIVING NEXT TEST(S)

TEST	LOAD	PROB.
3	150.000	.011

REVISED MEAN STRENGTH = 153.611, VAR = .366

I	X	FXL	PIS	PRS	DELPF	PF	PSM
13	65.000	.10000+01	.21624-07	.73320-08	.73320-08	.73320-08	.00000
14	70.000	.14904+06	.59252-07	.22072-07	.32233-07	.39565-07	.00000
15	75.000	.22400+07	.16393-06	.71571-07	.30770-07	.70266-07	.00000
16	80.000	.96400-01	.45920-06	.22995-06	.44267-07	.12055-06	.00000
17	85.000	.82700-01	.12973-05	.70920-06	.55395-07	.17595-06	.00000
18	90.000	.15300-01	.36915-05	.27446-05	.71246-07	.24719-06	.00000
19	95.000	.54800-02	.10539-04	.71169-05	.93616-07	.34081-06	.00000
20	100.000	.41220-07	.30181-04	.22639-04	.12441-06	.46572-06	.00000
21	105.000	[illegible]	[illegible]	.72288-04	.16717-06	.63239-06	.00000
22	110.000	[illegible]	.24893-03	.23131-03	.22528-06	.85767-06	.00000
23	115.000	[illegible]	.71461-03	.74172-03	.30600-06	.11637-05	.00000
24	120.000	.20200-07	.20472-02	.23771-02	.41758-06	.15813-05	.00000
25	125.000	[illegible]	.59797-02	.75597-02	.56975-06	.21510-05	.00000
26	[illegible]	[illegible]	.17843-01	.23323-01	.77205-06	.29230-05	.00000
27	[illegible]	[illegible]	[illegible]	.69530-01	[illegible]	.38774-05	.00000
28	[illegible]	[illegible]	[illegible]	.14945+00	.86301-06	.47554-05	.92701-03
29	[illegible]	[illegible]	.11842+00	.26975+00	.57770-06	.53331-05	.71962+00
30	[illegible]	[illegible]	[illegible]	.40332+00	.33050-06	.56636-05	.50372+00
31	[illegible]	[illegible]	[illegible]	.59361+00	.21291-06	.58760-05	.74034-01
32	[illegible]	.52700-06	[illegible]	.80450+00	.11310-06	.59892-05	.60197-02
33	[illegible]	[illegible]	[illegible]	[illegible]	.35146-07	.60246-05	.45704-03
34	[illegible]	[illegible]	[illegible]	.99234+00	.57102-08	.60303-05	.35648-04
35	[illegible]	[illegible]	[illegible]	.99923+00	.42868-09	.60307-05	.31784-05
36	[illegible]	[illegible]	[illegible]	.99993+00	.27514-10	.60307-05	.15433-07
37	[illegible]	[illegible]	[illegible]	.99999+00	.00000	.60307-05	.00000
38	[illegible]	[illegible]	[illegible]	.10000+01	.00000	.60307-05	.00000

TOTAL [illegible] .46527-05

RELIABILITY [illegible] LOAD LEVEL IS .9999995

[illegible] IS .9999940

CASE NO. 1 PSD GUST LOADS
INTENDED FAILURE PROB.. NO DISCREPANCY, NO TEST

INTENDED STRENGTH = 176.467
BASIC MEAN STRENGTH = 99.961

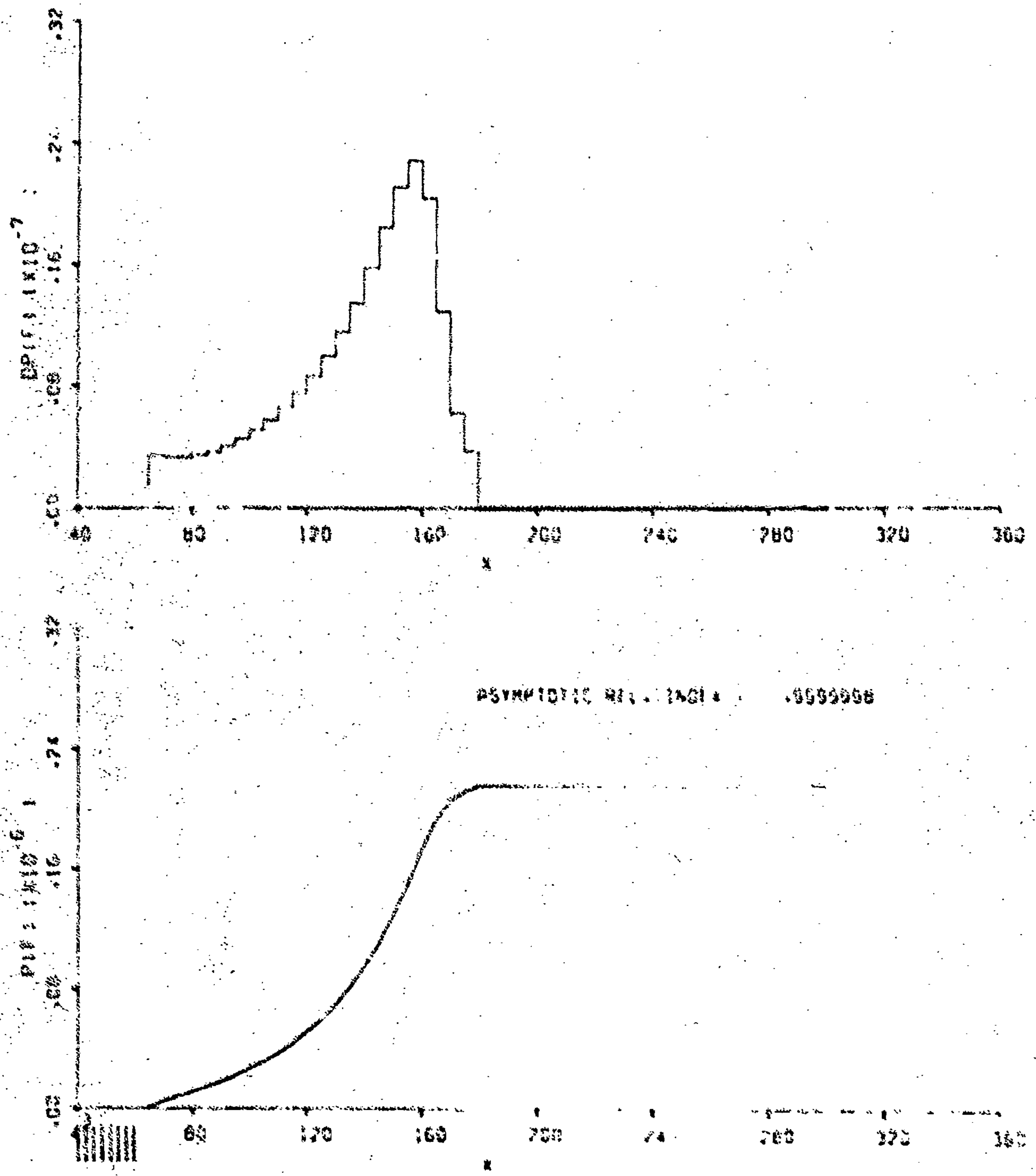


FIGURE 100. CALCOMP PLOTS OF C-141 EXAMPLE 1 (a) Intended reliability

CASE NO. 1 PSD GUST LOADS
PREDICTED FAILURE PROB. WITH PROB. DISCREPANCY, NO TEST

REVISED MEAN STRENGTH 161.993
VAR = .081

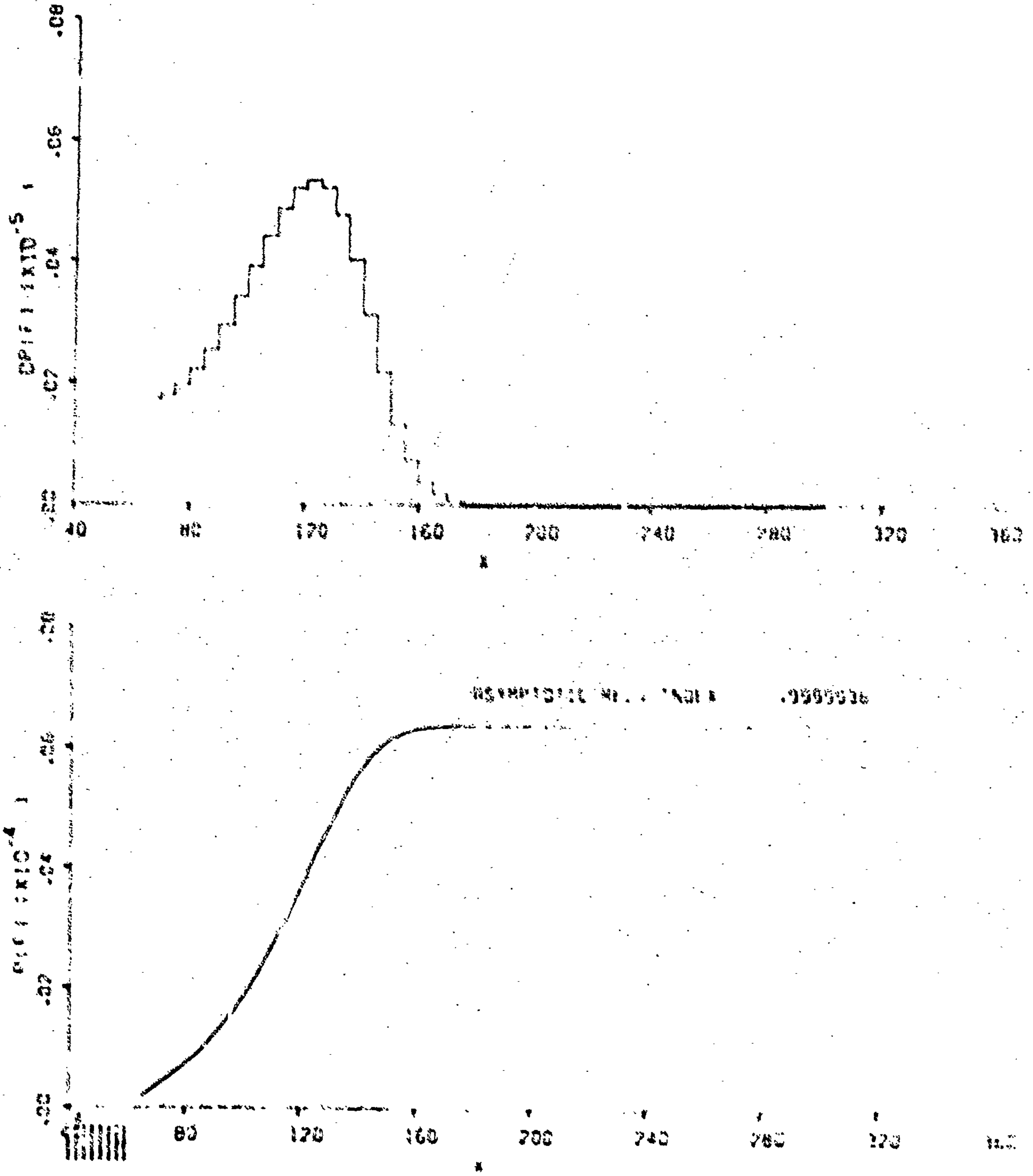
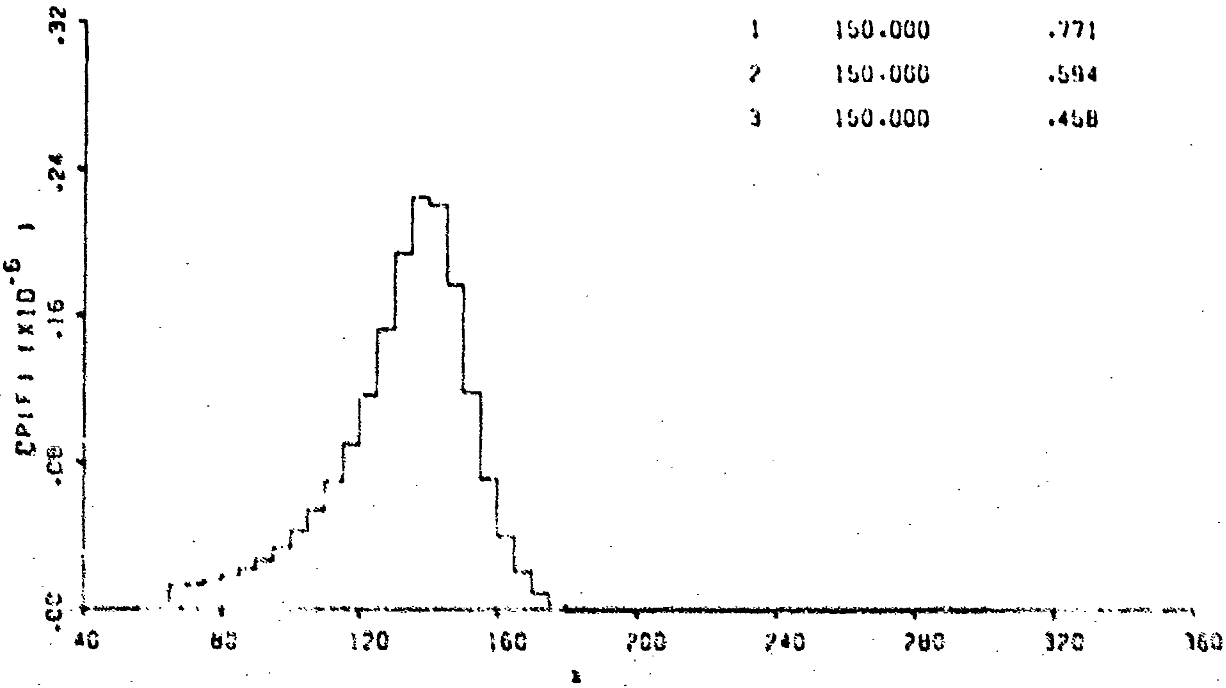


FIGURE 100 (CONTINUED) (b) With probable discrepancy, no test

CASE NO. 1 PSD GUST LOADS
UPDATED FAILURE PROB. AFTER 3 TESTS TO PASS SAME LOAD
TEST NO. 1 TEST FACTOR 1.500 TEST LOAD 150.000
REVISED MEAN STRENGTH 165.057
VAR .070
PROB. OF SURVIVING NEXT TESTS

TEST	LOAD	PROB.
1	150.000	.771
2	150.000	.594
3	150.000	.458



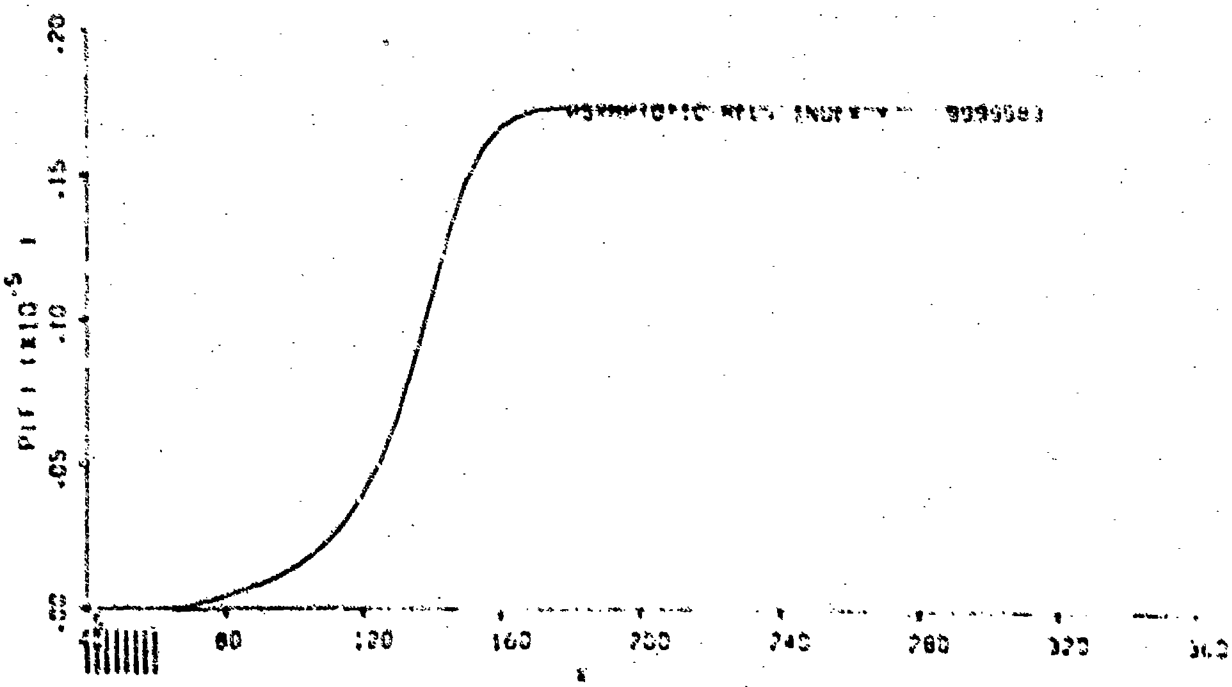
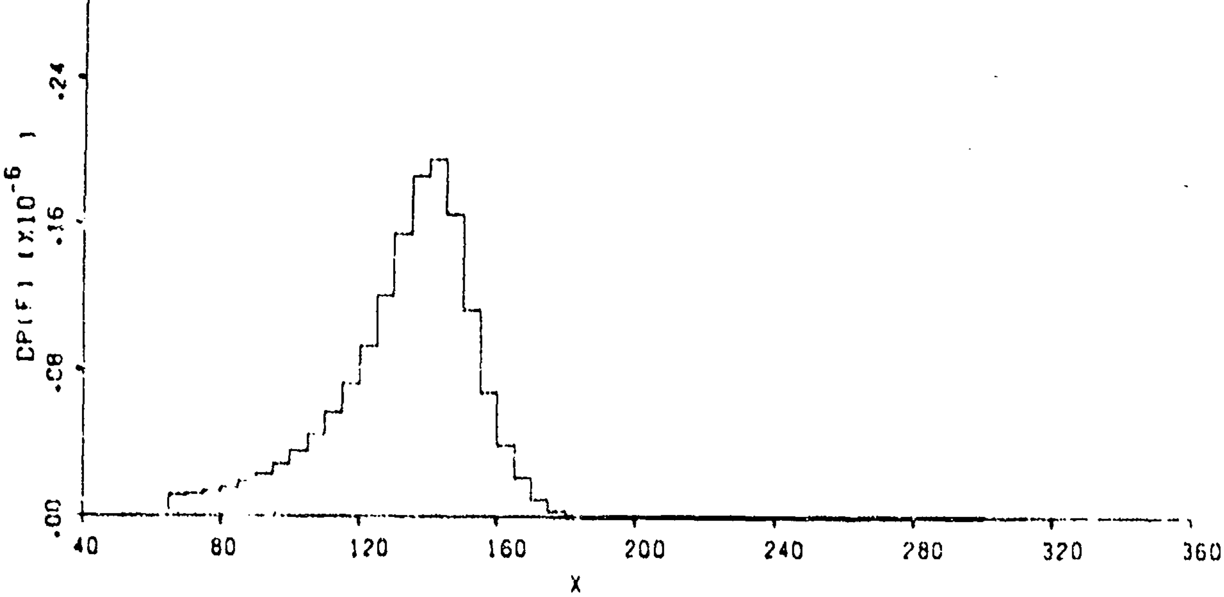


FIGURE 100 (CONTINUED) (c) After one test

CASE NO. 1 PSD GUST LOADS
UPDATED FAILURE PROB. AFTER 3 TESTS TO PASS SAME LOAD
TEST NO. 2 TEST FACTOR 1.500 TEST LOAD 150.000
REVISED MEAN STRENGTH = 165.881
VAR = .069
PROB. OF SURVIVING NEXT TESTS

TEST	LOAD	PROB.
2	150.000	.651
3	150.000	.[illegible]24



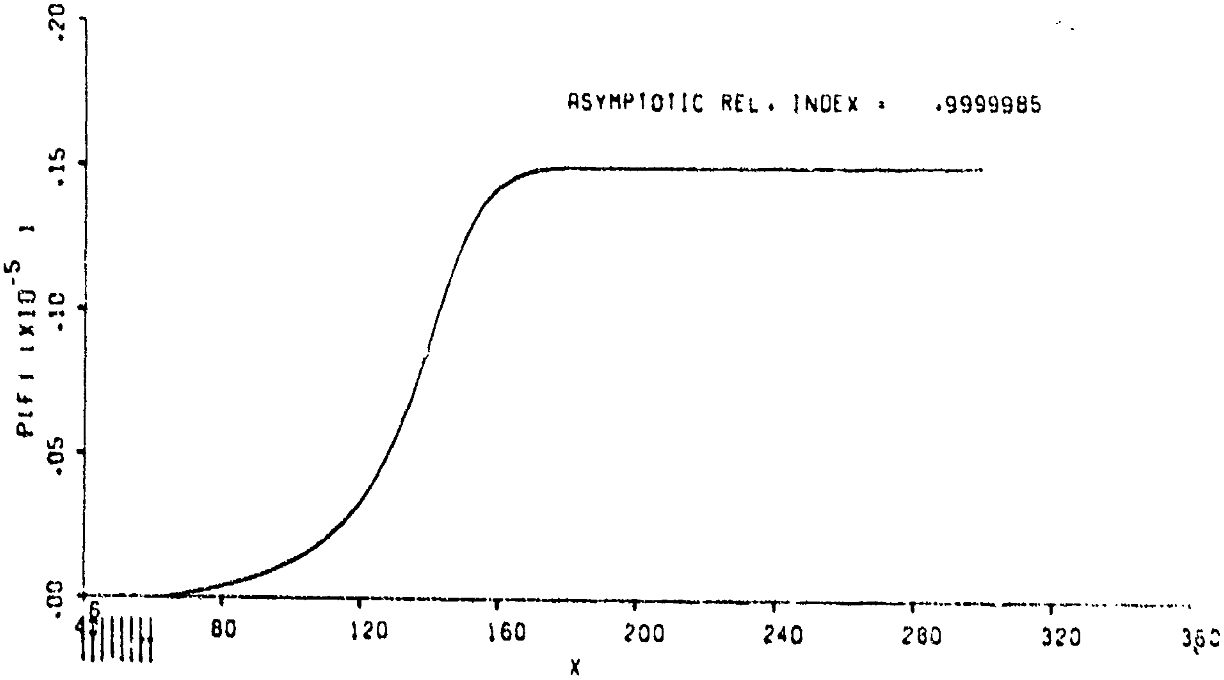
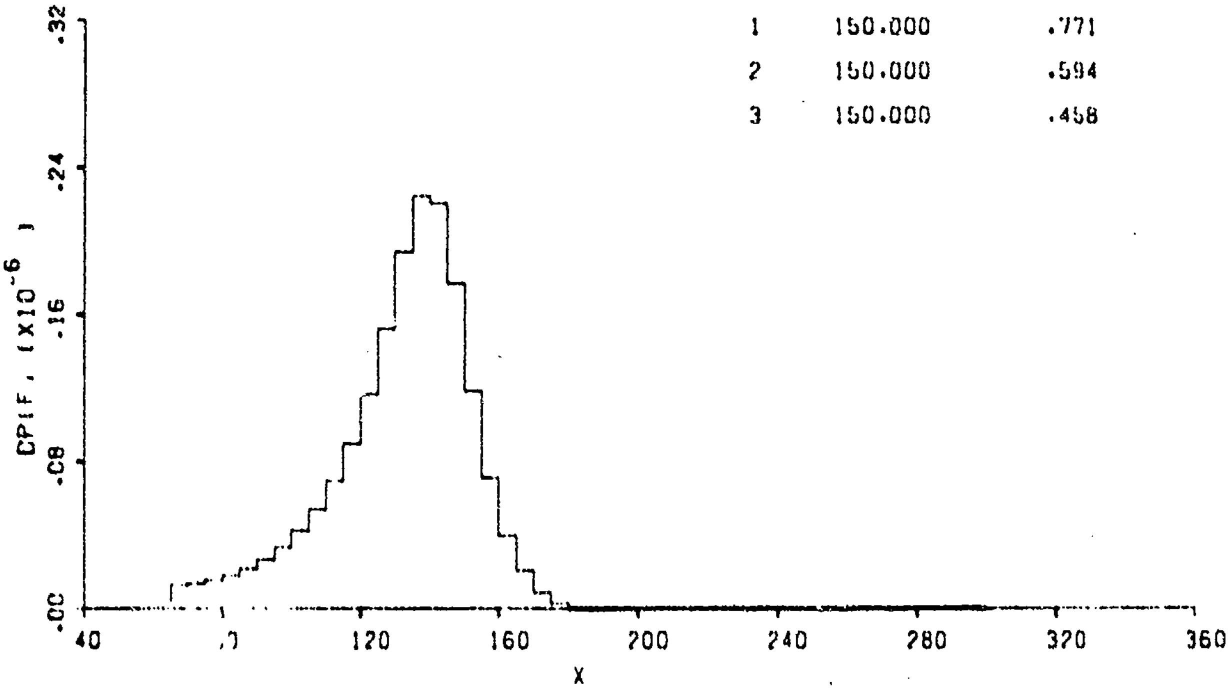


FIGURE 100 (CONTINUED) (d) After two tests

CASE NO. 1 PSD GUST LOADS
UPDATED FAILURE PROB. AFTER 3 TESTS TO PASS SAME LOAD
TEST NO. 1 TEST FACTOR 1.500 TEST LOAD 150.000
REVISED MEAN STRENGTH 165.057
VAR .070
PROB. OF SURVIVING NEXT TESTS

TEST	LOAD	PROB.
1	150.000	.771
2	150.000	.594
3	150.000	.458



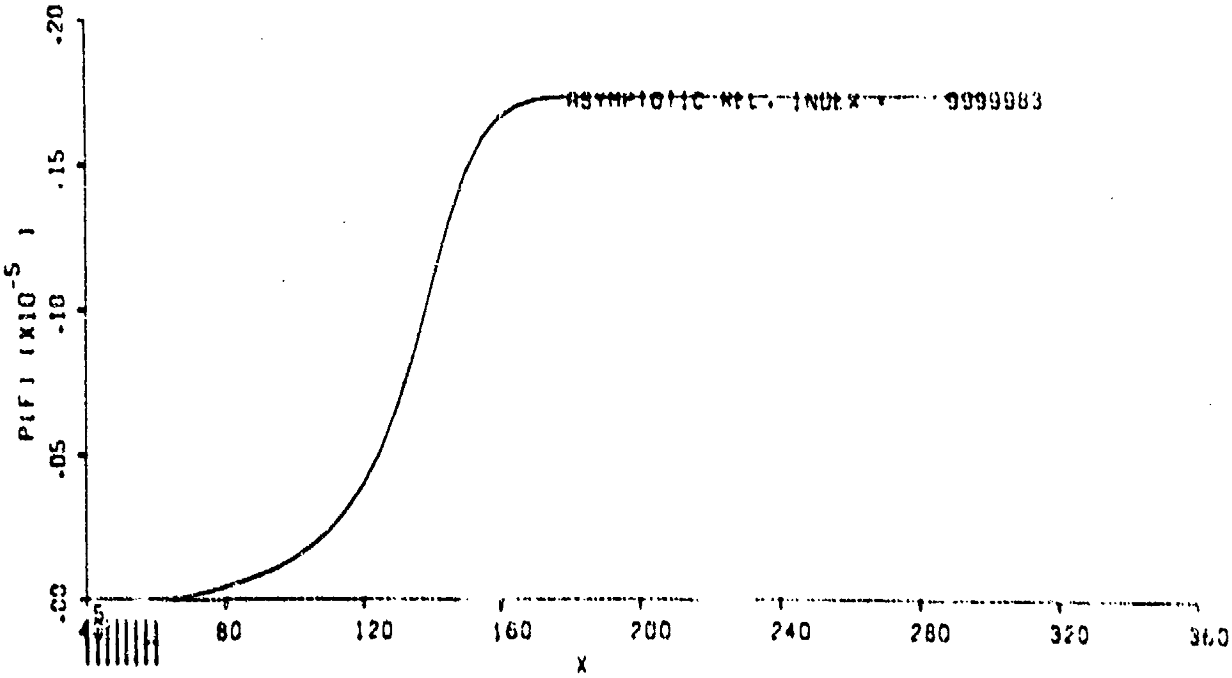


FIGURE 100 (CONTINUED) (c) After one test

CASE NO. 1 PSD GUST LOADS
UPDATED FAILURE PROB. AFTER 3 TESTS TO PASS SAME LOAD
TEST NO. 3 TEST FACTOR 1.500 TEST LOAD 150.000
REVISED MEAN STRENGTH - 166.424
VAR = .068
PROB. OF SURVIVING NEXT TESTS

TEST	LOAD	PROB.
3	150.000	.867

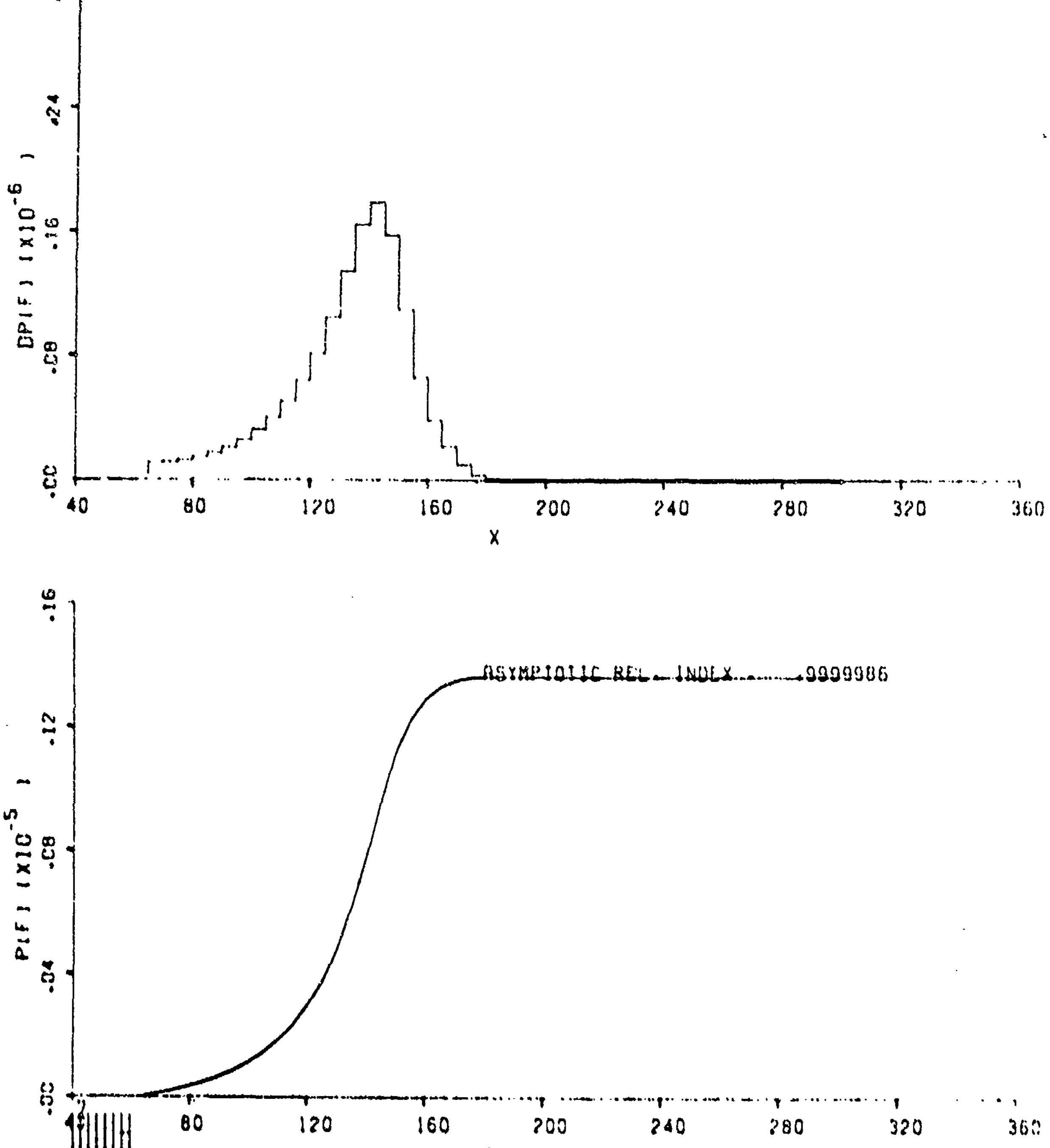


FIGURE 100 (CONCLUDED) (e) After three tests

CASE NO. 4 PSD GUST LOADS
PREDICTED FAILURE PROB. WITH PROB. DISCREPANCY, NO TEST

REVISED MEAN STRENGTH = 144.679
VAR = .219

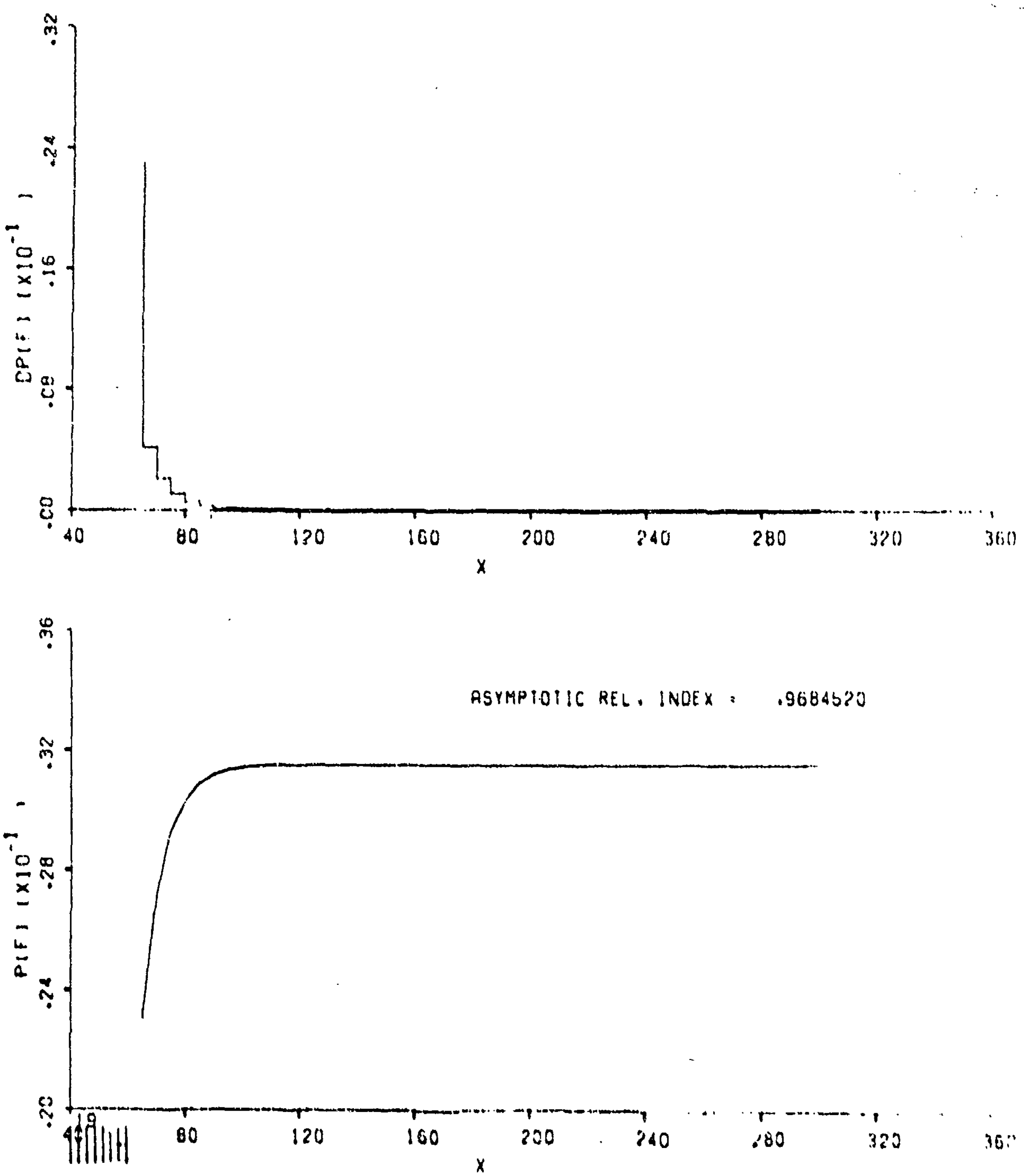
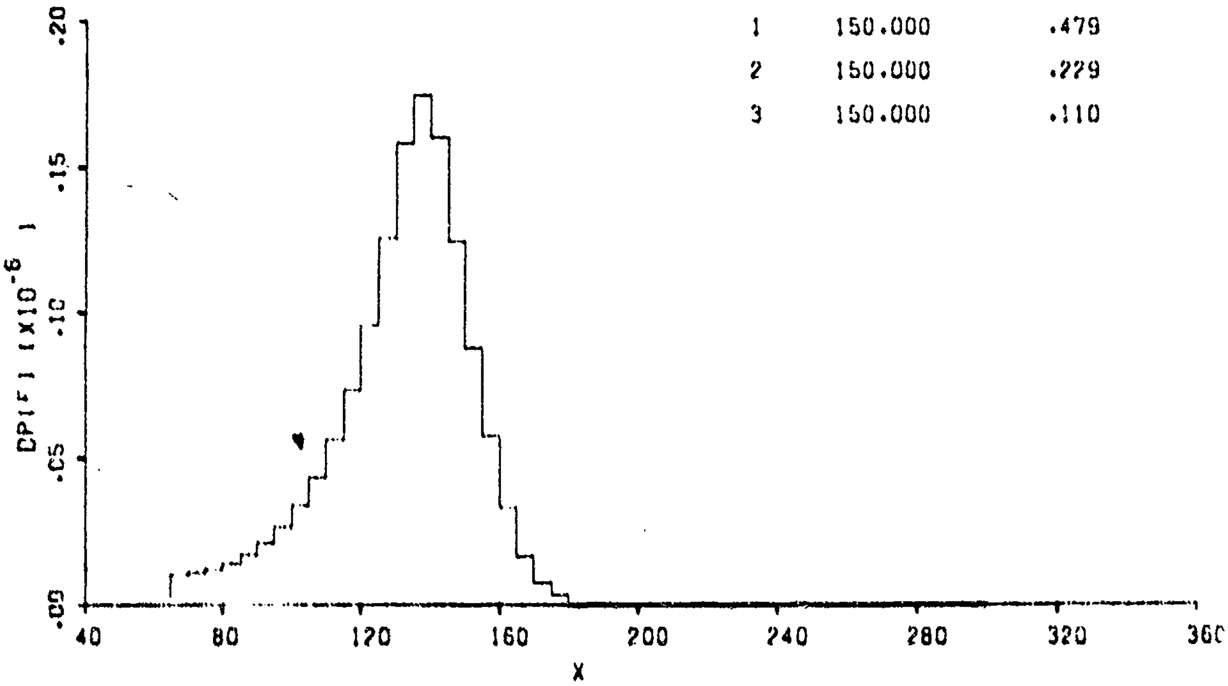


FIGURE 101 CALCOMP PLOTS OF C-141 EXAMPLE 4 (a) With probable discrepancy, no test

CASE NO. 4 PSD GUST LOADS
UPDATED FAILURE PROB. AFTER 3 TESTS TO PASS SAME LOAD
TEST NO. 1 TEST FACTOR 1.500 TEST LOAD 150.000
REVISED MEAN STRENGTH = 169.716
VAR = .079
PROB. OF SURVIVING NEXT TESTS

TEST	LOAD	PROB.
1	150.000	.479
2	150.000	.229
3	150.000	.110



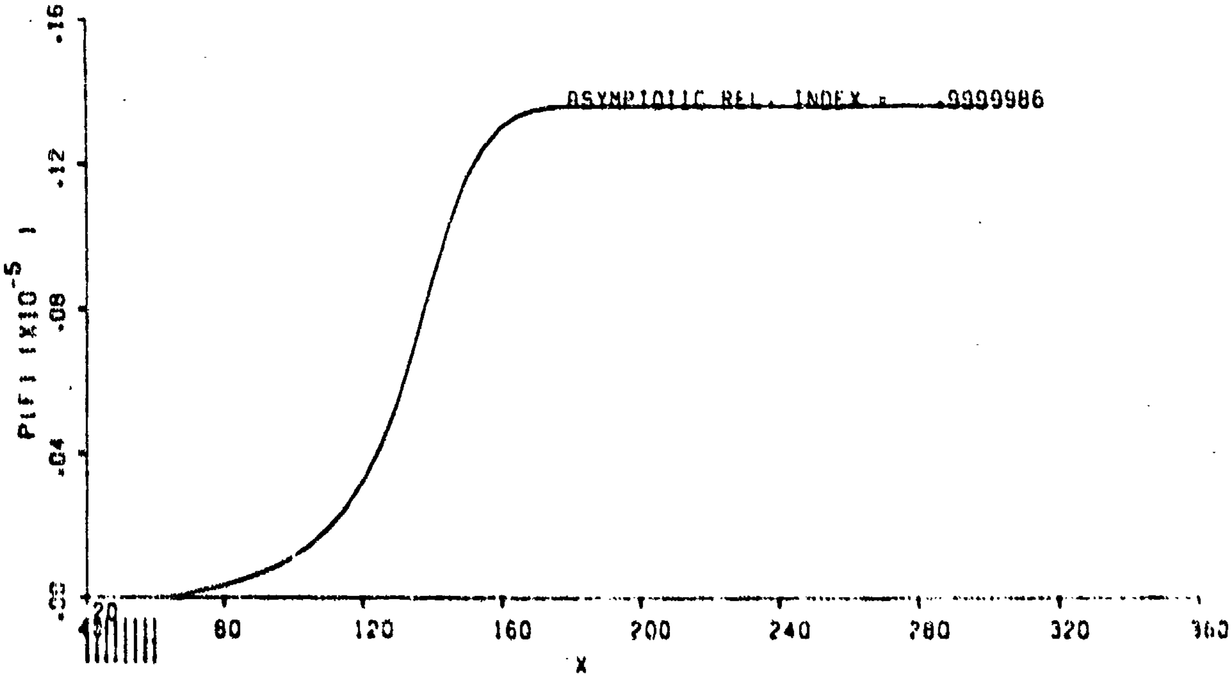


FIGURE 101 (CONTINUED) (b) After one test

CASE NO. 4 PSD GUST LOADS
UPDATED FAILURE PROB. AFTER 3 TESTS TO PASS SAME LOAD
TEST NO. 2 TEST FACTOR 1.500 TEST LOAD 150.000
REVISED MEAN STRENGTH = 170.992
VAR = .076
PROB. OF SURVIVING NEXT TESTS

TEST	LOAD	PROB.
2	150.000	.891
3	150.000	.794

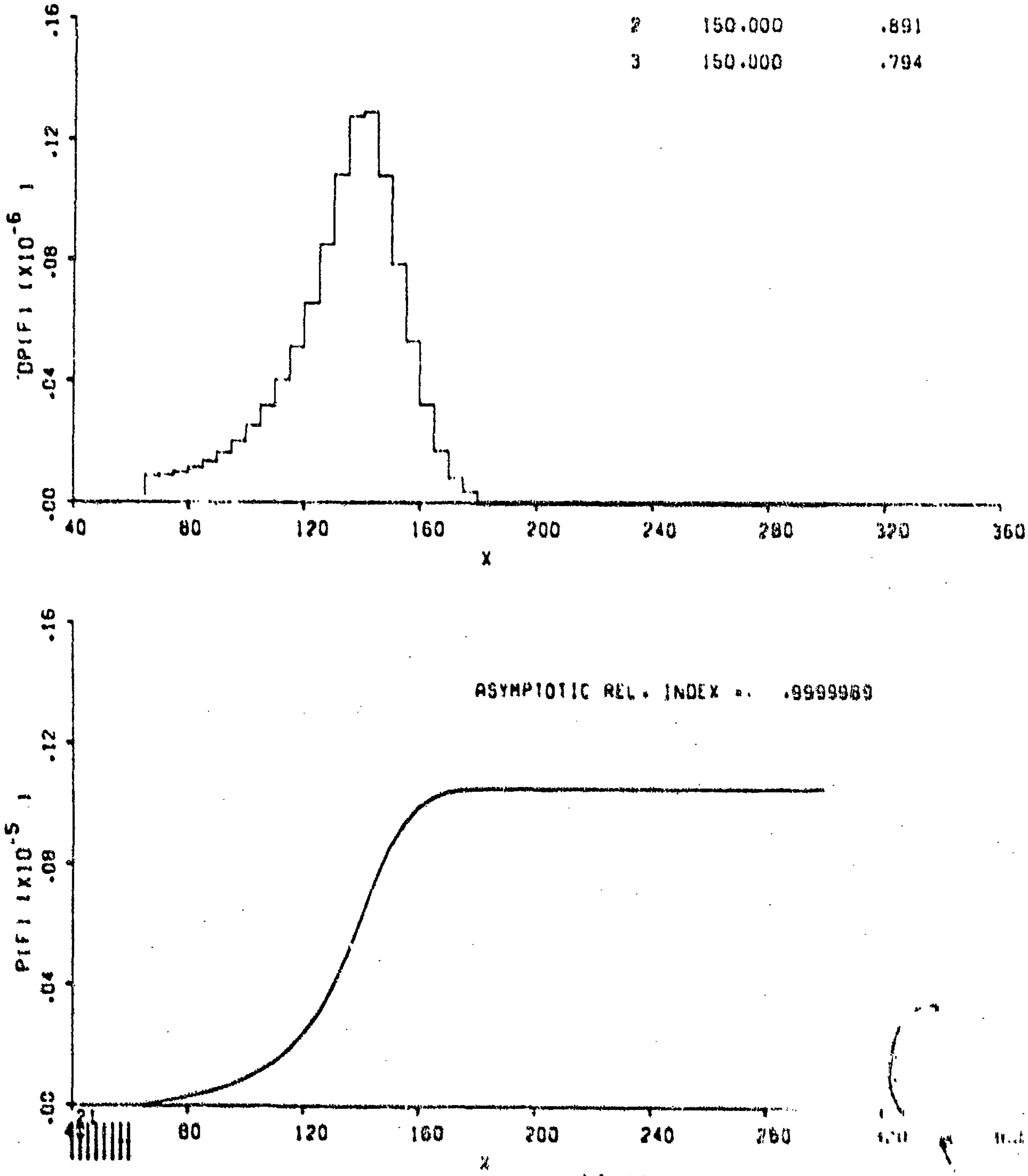
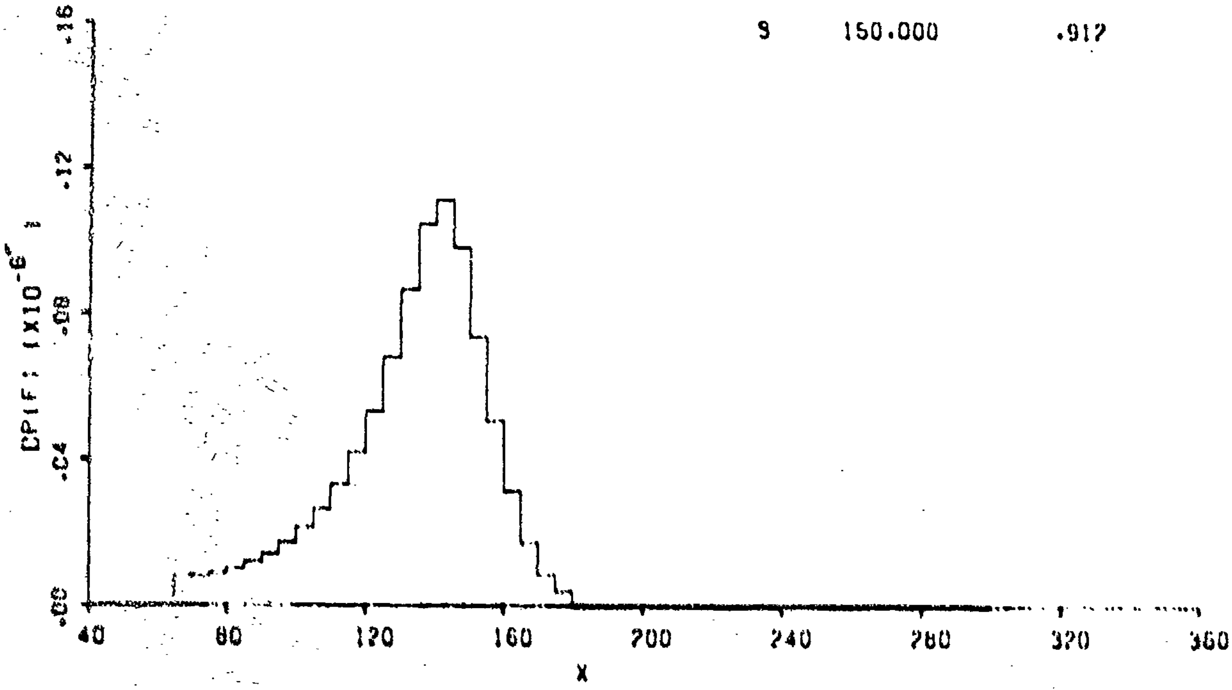


FIGURE 101 (CONTINUED) (c) After two tests

CASE NO. 4 PSD GUST LOADS
UPDATED FAILURE PROB. AFTER 3 TESTS TO PASS SAME LOAD
TEST NO. 3 TEST FACTOR 1.500 TEST LOAD 150.000
REVISED MEAN STRENGTH = 171.757
VAR = .074
PROB. OF SURVIVING NEXT TESTS

TEST	LOAD	PROB.
5	150.000	.917



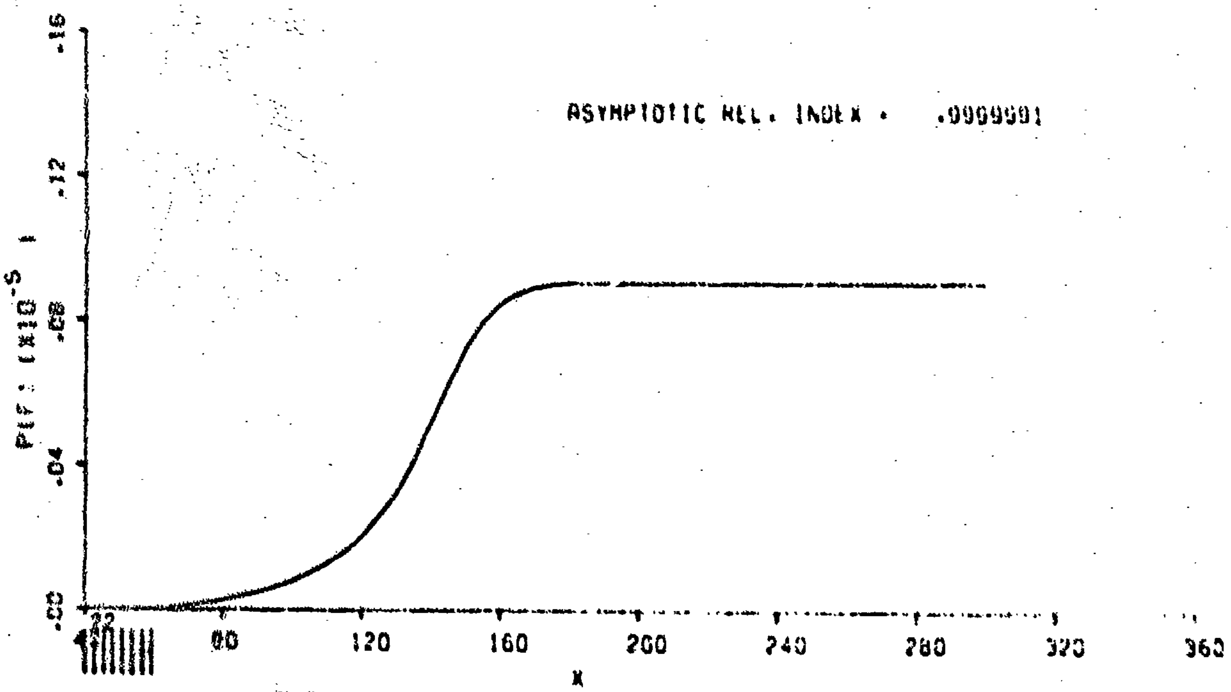


FIGURE 101 (CONCLUDED) (d) After three tests

TABLE XLIII

SUMMARY OF RESULTS OF C-141 EXAMPLES

CASE	NOTES	RELIABILITY				
		NO ERR	NO TEST	1 TEST	2 TESTS	3 TESTS
	MODIFIED PROGRAM, 3 TESTS SURVIVING 150, DOUBLE FAMILY GUMBEL STRENGTH, PSD GUST LOADS SPECTRA					
1	Gumbel Error, β Mean = .95 (.05 of total)	.9999998	.9999936	.9999983	.9999985	.9999986
2	Gumbel Error, β Mean = .50 (.05 of total)	.9999998	.9911144	.9999972	.999997[illegible]	.9999979
3	Gumbel Error, β Mean = .50 (.10 of total)	.9999998	.9830682	.9999946	.9999955	.9999960
4	Standard Jablecki Error	.9999998	.9684520	.9999965	.9999989	.9999991
	MODIFIED PROGRAM, 3 TEST FAILURES AT 150, SAME STRENGTH AND LOADS SPECTRA					
5	Gumbel Error as 1	.9999998	.9999936	.9999959	.9999950	.9999946
6	Gumbel Error as 2	.9999998	.9911144	.9999949	.9999945	.9999943
7	Gumbel Error as 3	.9999998	.9830682	.9999928	.9999932	.9999932
8	Standard Jablecki Error	.9999998	.9684520	.9999948	.9999942	.9999940
	ORIGINAL PROGRAM, 3 TESTS SURVIVING 150, WEIBULL STRENGTH SPECTRUM, STANDARD JABLECKI ERROR					
9	Weibull Loads Spectrum	-	-	.9999969	.9999981	.9999986
10	Log-Normal Loads Spectrum	-	-	.9999972	.9999983	.9999986

APPENDIX V
LOAD AND STRENGTH DATA

A5.1 Introduction

This Appendix gives examples of the types of data available for the derivation of loads and strength distributions, and the way in which suitable simple statistical equations can be fitted to such data collections. The double-family techniques of Appendix I have been used for the examples, with the specific equation of the Gumbel distribution (the first asymptotic theory of extremes).

For the load distributions, the distribution of maximum values has been chosen as giving better representation of the most significant region - the high load end of the distribution. In the case of the strength data, the most significant area is that of low strength and the distribution of minimum values has been selected. The logic of this choice is obvious: failure is most likely to be the result of a high load or a low strength; the exact representation of the low loads and high strengths will not contribute to a better assessment of the reliability.

Irrespective of any formal mathematical arguments, it is essential that the equations used do provide a "reasonable" fit to the data. Assumptions of particular distributions without convincing evidence of their validity can only lead to repetition of Disraelis famous criticism.*

A5.2 Load Data

a. Gust and maneuver load distributions for the C-141A have been described in Section X. Data for landing impact, taxi, take-off and landing run-out are described in this Appendix. All four load conditions have been used for main landing gear loads, and the three ground conditions have been used to derive wing root bending moments.

*"There are three kinds of lies: lies, damned lies and statistics."

b. Landing Impact

Sink rate data from 5345 Ground Loads Survey landings have been assembled and fitted by a double-family Gumbel distribution as shown in Figure 102.

These results have then been combined with fuel and cargo data from the usage analysis to determine the vertical and drag loads on the main landing gear, the resulting distributions being presented in Figure 103. The design lifetime of 12000 landings is used as the return period. The original basic design case for the gear was a 10 ft/sec landing at design landing weight (257,100 lb.). This limit load and the design ultimate (1.5 times limit) load are shown for comparison with limit and omega conditions defined at the suggested probabilities of 10^0 and 10^{-3} per lifetime.

It can be seen that the original design limit and ultimate conditions have observed probabilities of approximately 10^{-3} and 10^{-6} per lifetime, so that the present design limit condition approximates the suggested omega (overload) condition, and the present ultimate condition exceeds the omega condition by 50 per cent.

c. Taxi, Takeoff and Runout

An arbitrary 2.0g static taxi requirement provided the design down-bending case for the C-141 inner wing and landing gear vertical load. Power spectral analyses were conducted to assess the probability of such a condition, using the methods of reference 16. Four types of surface were assumed, ranging from "prepared-smooth" to "unprepared-rough". A 20 knot taxi speed was assumed; the takeoff and runout velocities were varied with weight, and the takeoff analysis included appropriate lift.

The usage data were then employed to solve for the wing and gear load spectra, using the following exceedence equations:

Taxi:

$$N(y) = N_{o_v} \cdot T \cdot \sum_{RW=1}^{4} P_{RW} \cdot \exp\left\{-\frac{1}{2}\left(\frac{y-\bar{y}}{\sigma_{v_{RW}}}\right)^2\right\} \qquad \text{A5.1}$$

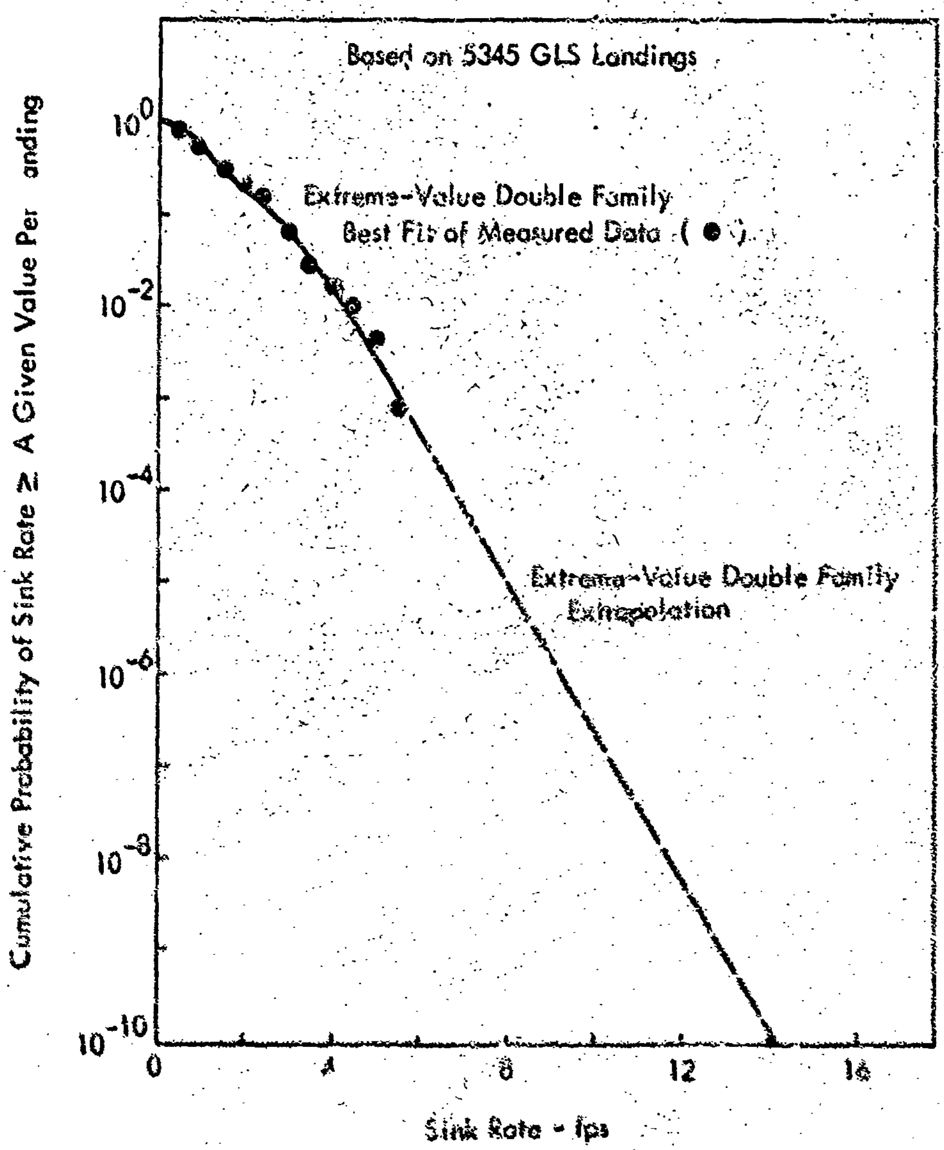


FIGURE 102 C-141 LANDING IMPACT SINK RATE SPECTRUM

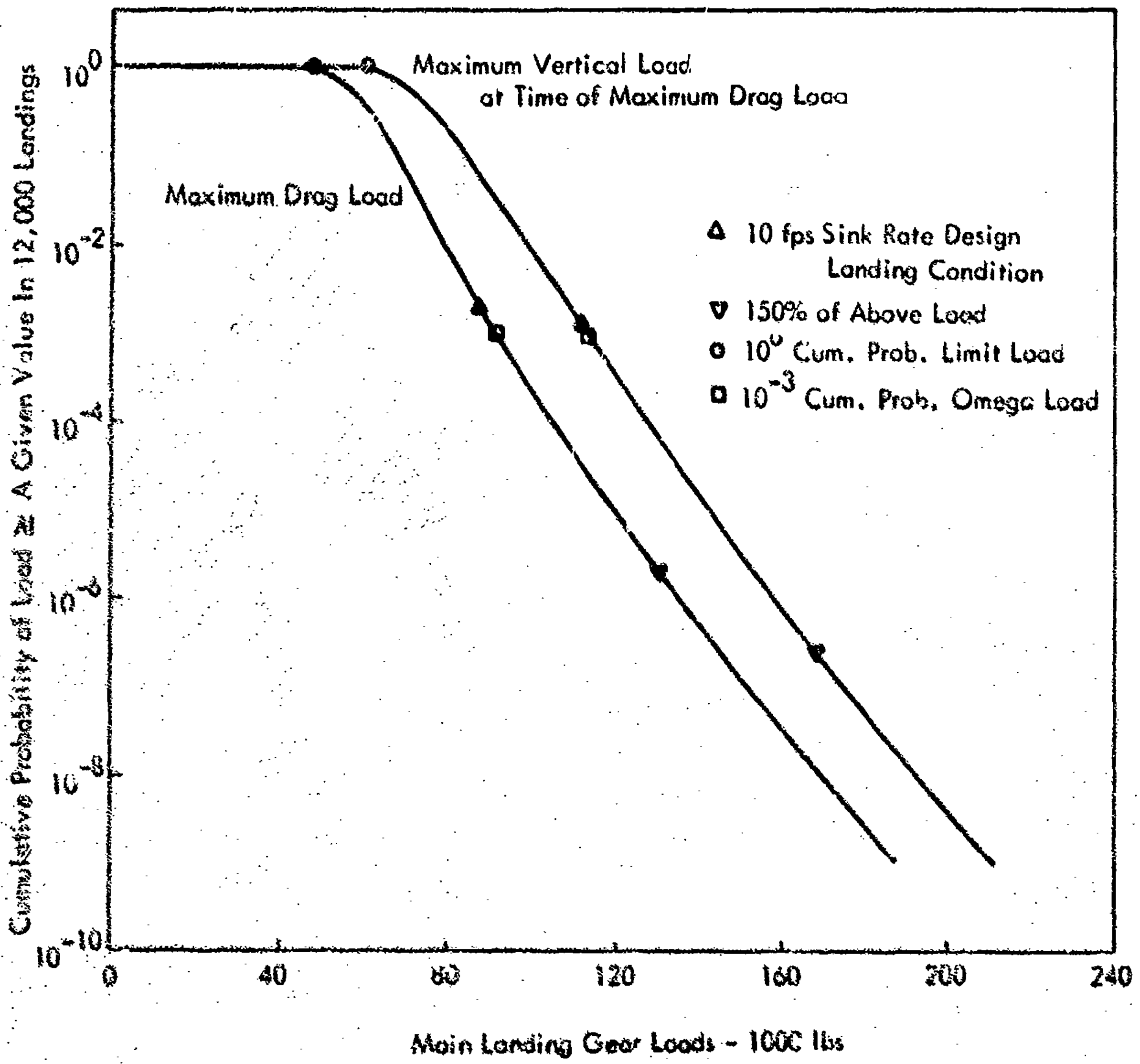


FIGURE 103 C-141 MAIN LANDING GEAR LANDING IMPACT LOADS SPECTRA

Take-off and run-out:

$$N(y) = \sum_{v=1}^{4} P_v \cdot N_{o_v} \cdot T\left[\sum_{RW=1}^{4} P_{RW} \cdot \exp\left\{-\frac{1}{2}\left(\frac{y-\bar{y}}{\sigma_{v_{RW}}}\right)^2\right\}\right] \qquad \text{A5.2}$$

Where:

$N(y)$ = peak spectrum for a particular data block (fuel-cargo combination)

N_o = characteristic frequency of aircraft response for a given data block and velocity

T = total time in a particular data block

P_{RW} = fractional time for each of the four runway roughness levels

P_V = fractional time for a particular data block/velocity combination

y = total peak load

$\bar{y}$ = 1.0g static load for a particular data block

$\bar{y}_v$ = 1.0g mean load for a particular data block and velocity

$\sigma_{v_{RW}}$ = r.m.s. incremental load response variable for a given data block, velocity and runway roughness level.

Figures 104 and 105 show the resultant wing downbending spectrum and the main gear vertical load spectrum, respectively. Loads corresponding to the suggested limit and omega levels are indicated, the former being less than two-thirds of the original 2.0 static taxi loads while the latter are less than three-quarters of these design loads.

It is also seen that the original design limit load has a probability of exceedance of less than 10^{-7} per 12000 landing lifetime, suggesting that the 2.0g static taxi case is very conservative compared with probabilistic taxi, take-off and landing run-out loads.

If spectral density analyses are used to derive design conditions, care must be taken to ensure that the basic parameters do represent all possible sources of loading, including such events as towing over damaged surfaces, etc.

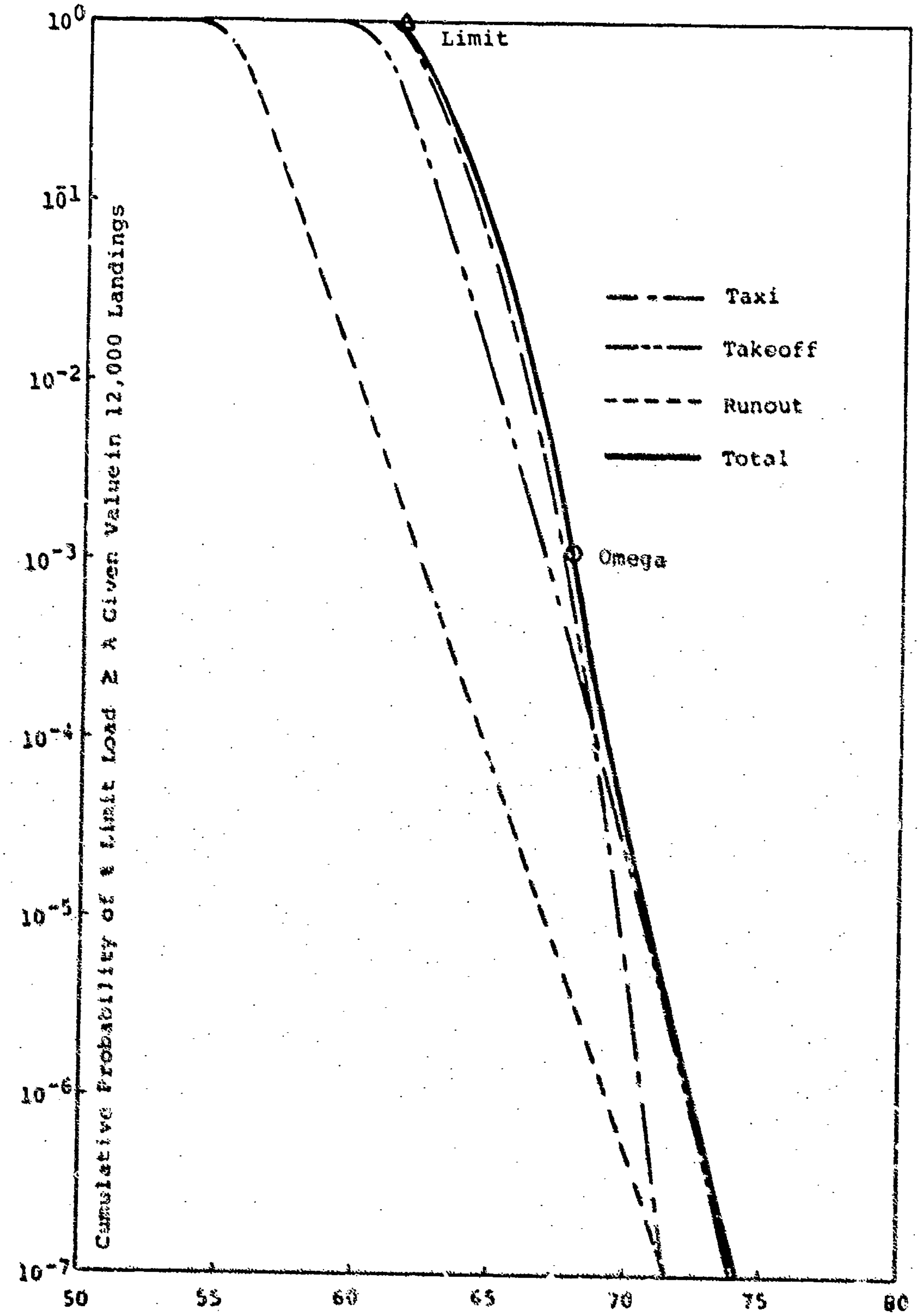


FIGURE 104 C-141 WING ROOT DOWNBENDING PROBABILITY SPECTRA FOR TAXI, TAKEOFF AND RUNOUT

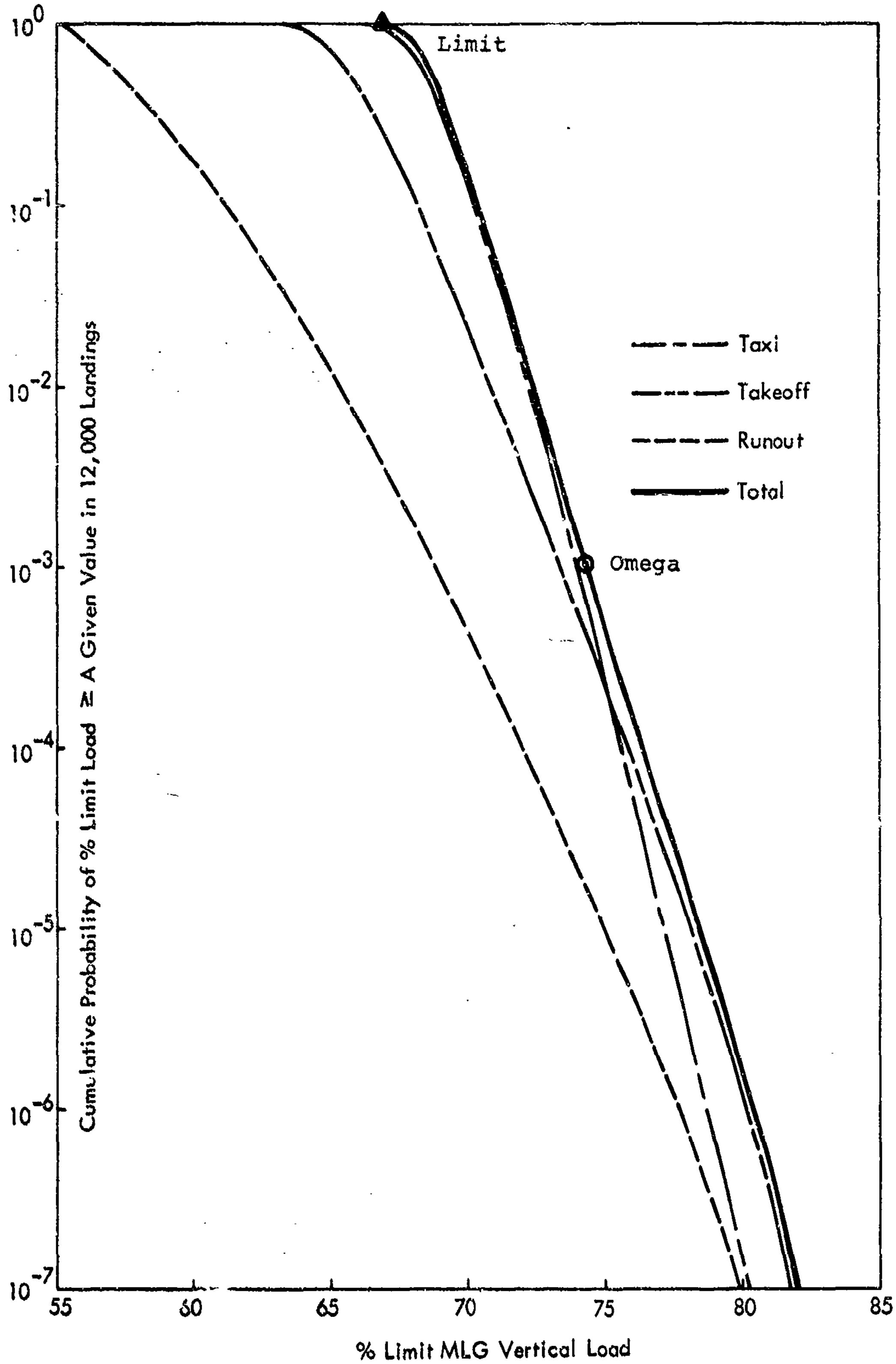


FIGURE 105 C-141 MAIN LANDING GEAR VERTICAL LOAD PROBABILITY SPECTRA FOR TAXI, TAKEOFF AND RUNOUT

A5.3 Material Strength

a. Four typical sets of test results have been extracted and subjected to analysis to derive equations for double-family Gumbel distributions.

b. Aluminum Alloy 7079-T6

Figure 106 (a) shows the frequency distribution of the 183 observations, with the corresponding probabilities of a lower value in Figure 106(b), using the transformed parameter, Y, to obtain a plot on the Gumbel paper scale. The fitted single-family distribution is represented by the straight line on this latter figure, and is also shown on the frequency distribution figure.

The double-family distribution, shown on both figures, was derived from the Lockheed-Georgia Company program EVDIS and shows better correlation in the significant region of the low-strength tail. An even better fit could easily be obtained by some further adjustment of the weaker family.

c. 300 VAR Steel, 280 KSI

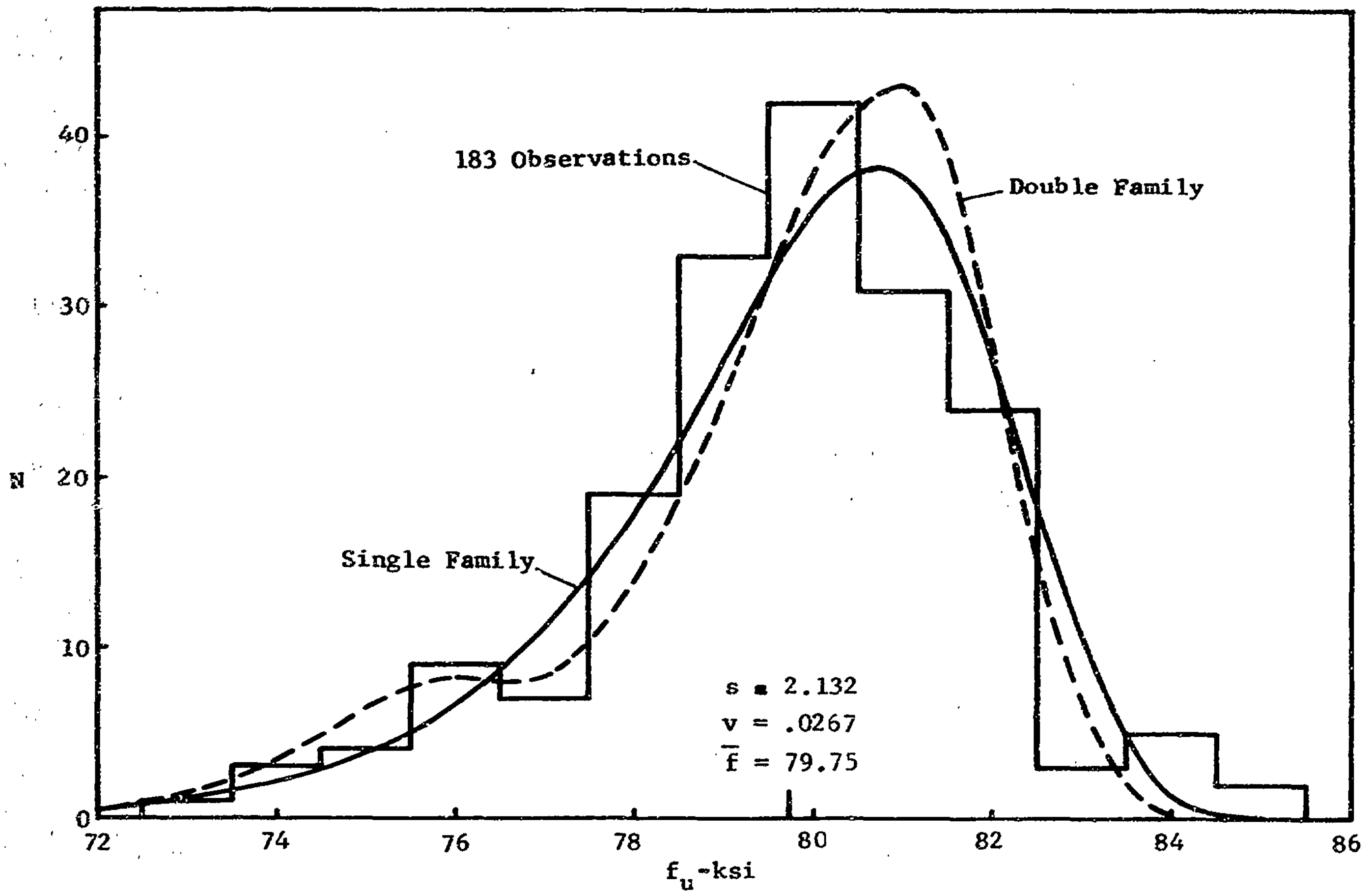
Figures 107 show similar improvements over the use of a single family distribution. The fitted double family has the smaller sub-family at the high strength end.

d. Titanium Sheet at 80°F

Figures 108 contain corresponding functions for this material.

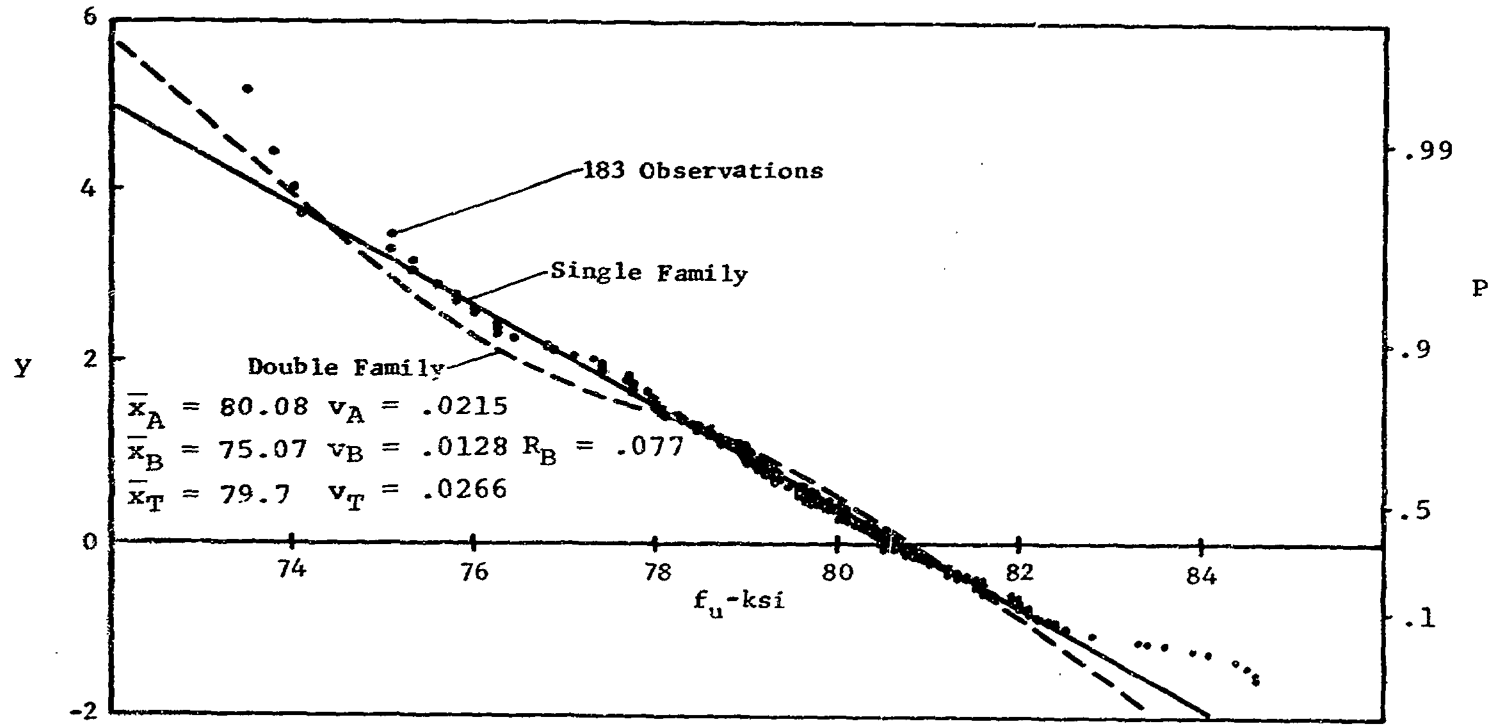
e. Boron composite specimens in longitudinal flexure

A group of 68 test results, from specimens fabricated over a period of almost one year, was assembled and analyzed in order to compare the characteristics with those of typical metallic materials. Figure 109(a) shows the fitted normal distribution; this is an excellent fit in the vicinity of the mode, but misses the three lowest values completely, as shown in the lower figure. Figure 109(b) illustrates the better fit obtained with a (skewed) Gumbel distribution of minima. Two types of double-family distribution were then tried; two families added, as



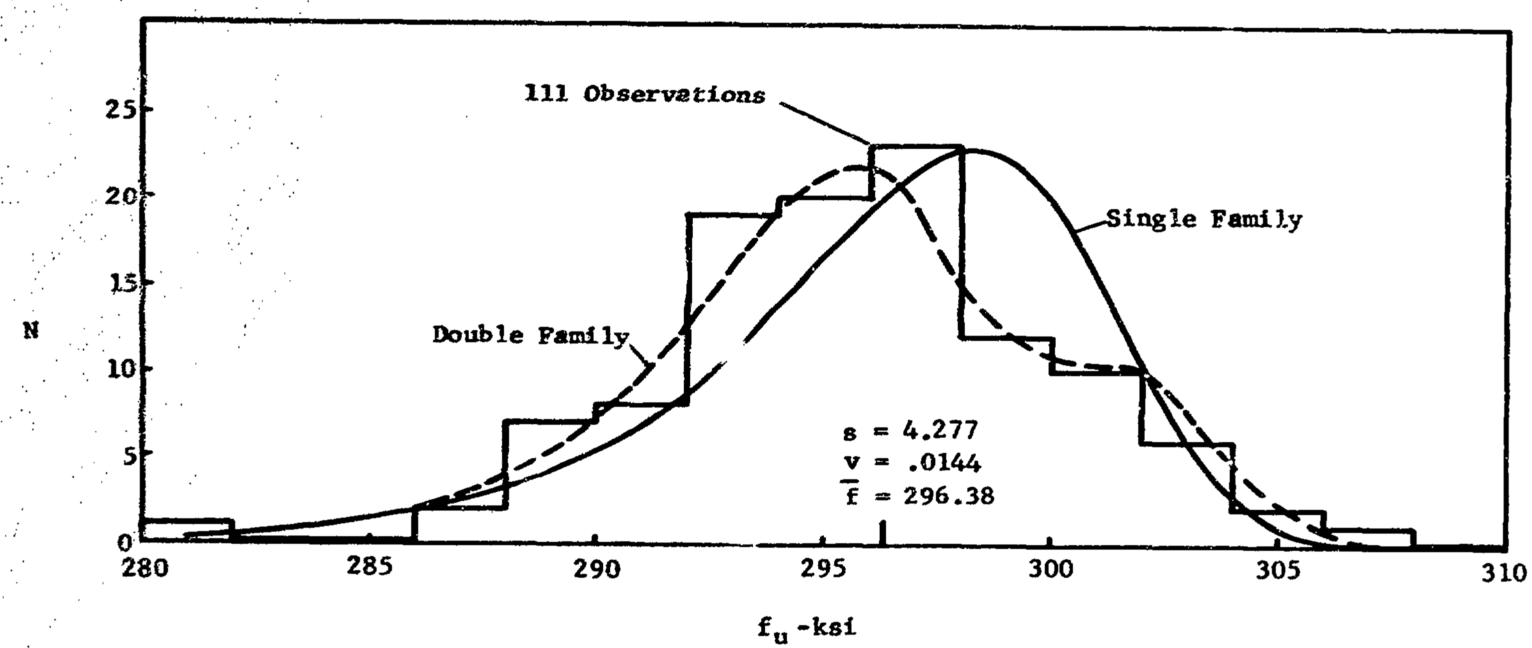
(a) FREQUENCY DISTRIBUTION

FIGURE 106 Aluminum 7079-T6 Strength



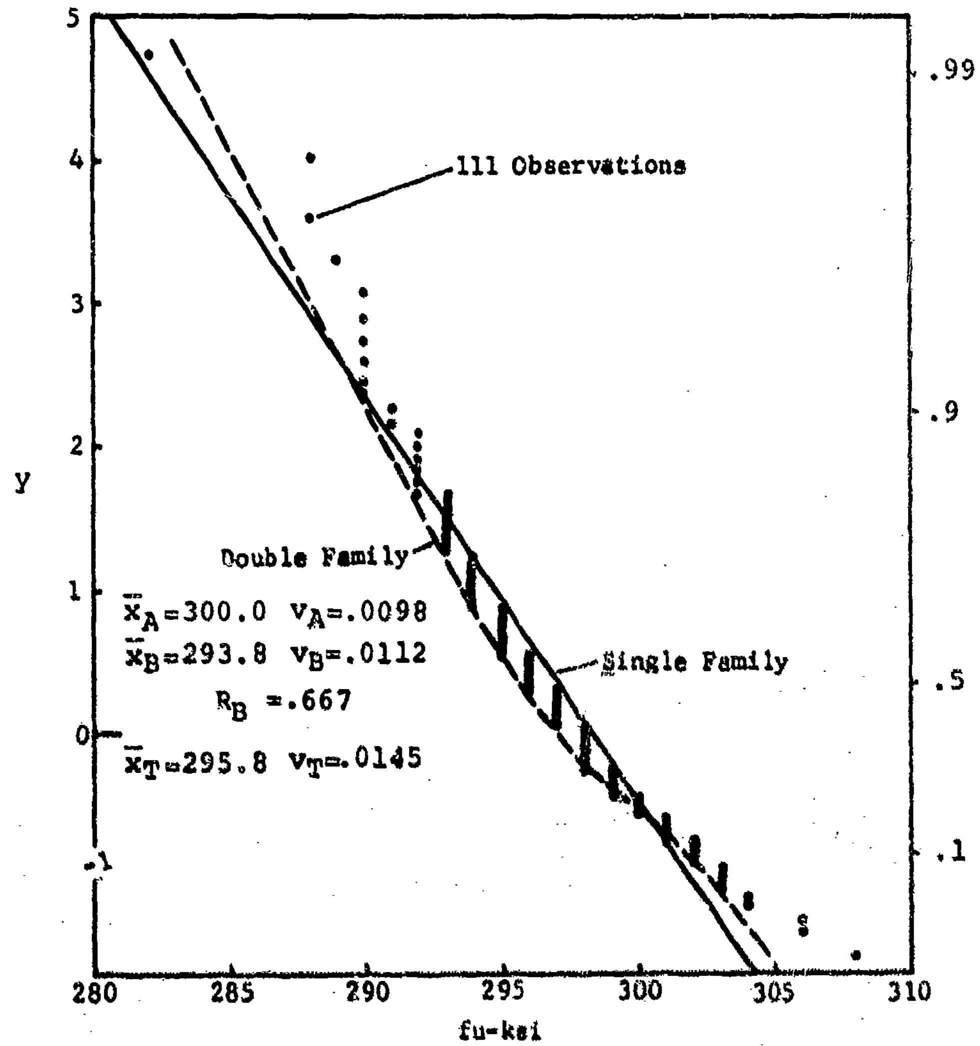
(b) CUMULATIVE DISTRIBUTION

FIGURE 106 (CONCLUDED)



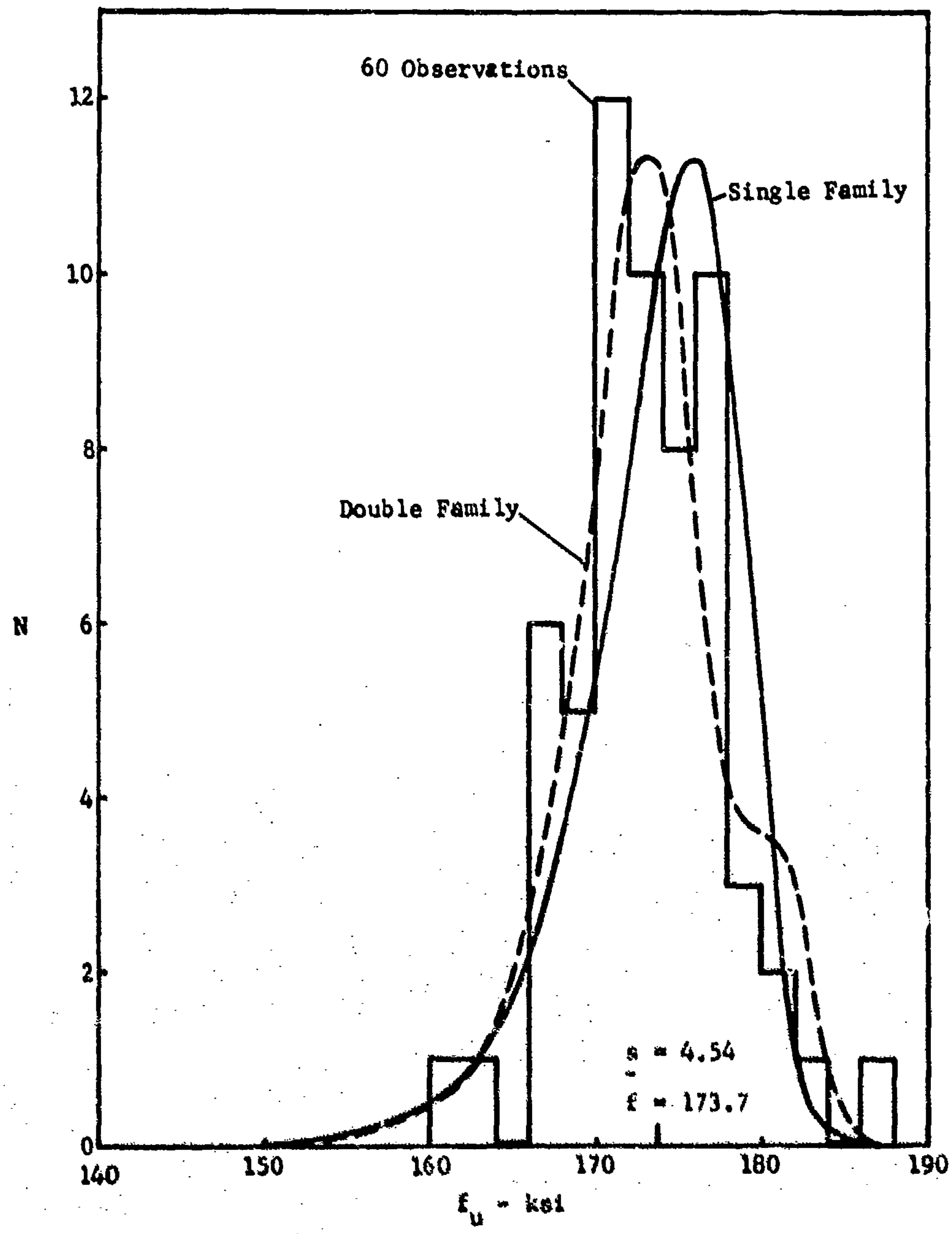
(a) FREQUENCY DISTRIBUTION

FIGURE 107 300 VAR STEEL STRENGTH



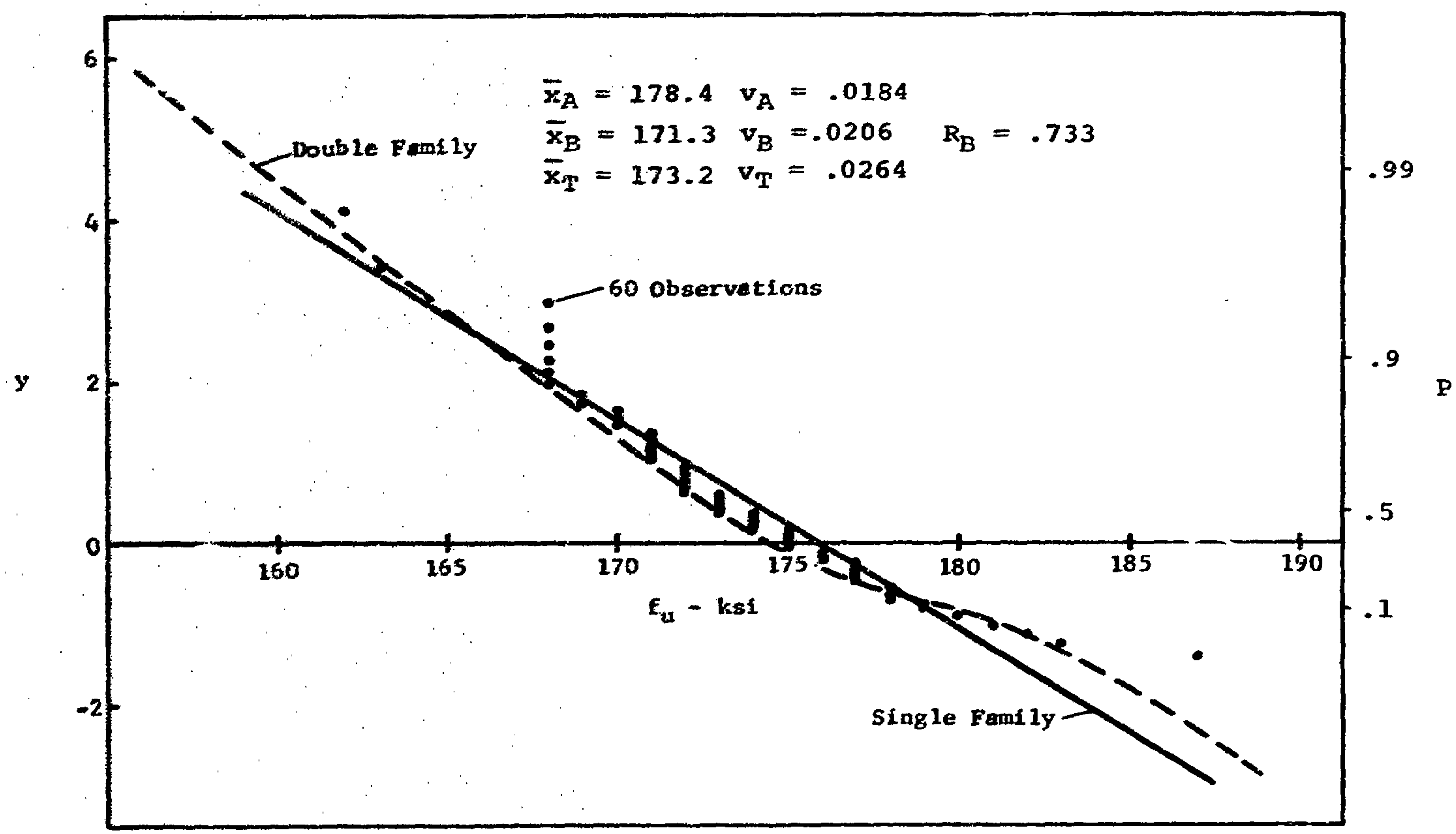
(b) CUMULATIVE DISTRIBUTION

FIGURE 107 (CONCLUDED)



(a) FREQUENCY DISTRIBUTION

FIGURE 108 TITANIUM SHEET STRENGTH



(b) CUMULATIVE DISTRIBUTION

FIGURE 108 (CONCLUDED)

shown in figure 109(c), results in no improvement; with family B subtracted from Family A, however, as illustrated by figure 109(d), a better fit is obtained.

g. Table XLIV summarizes the results of the study of material strength data. The 99 per cent exceedence values (ignoring the confidence level) are shown for comparison purposes. In the case of the boron composite, whose skewness is the most pronounced, it can be seen that the assumption of normality could lead to a design value which is significantly greater than that derived from a skewed distribution.

A5.4 Joint Strength Data

a. A series of test data sets was examined as a possible approach to the selection of a fabrication variation. In many instances, groups of riveted joint specimens will be made from material of a single batch, so that relatively little material strength scatter could be anticipated.

b. AD5 rivet, t = 0.05 inches

A set of twenty test results on riveted joints using AD5 rivets in 0.05 inch 7075-T6 sheet was analyzed with the results shown in Figure 110.

c. D6 rivet, t = .09 inches

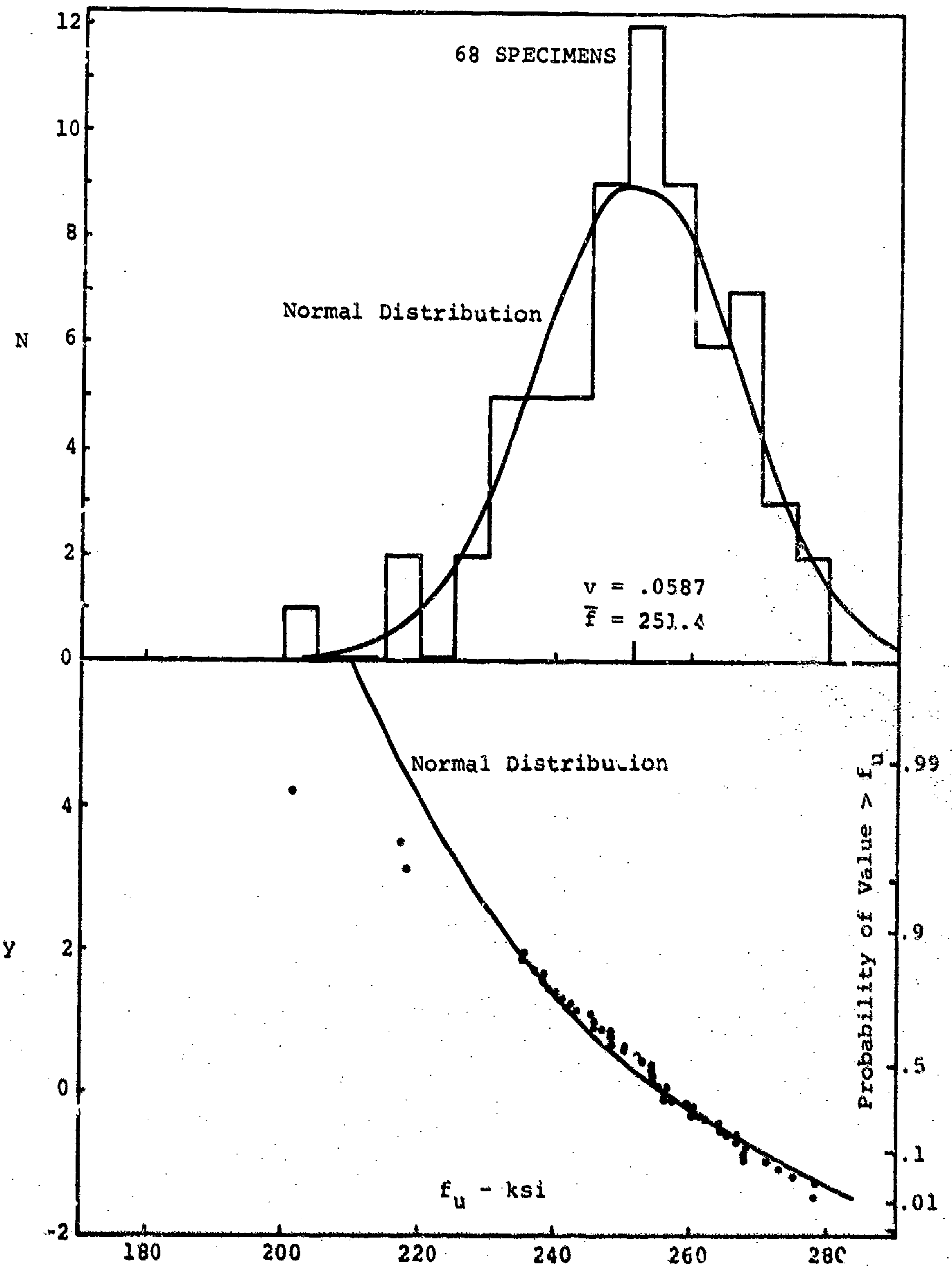
A second group of ten riveted joint results was also analyzed, figure 111 showing the ability of the double-family method to represent distributions of a distinctly bi-modal character; the number of data points is too small for definitive results.

d. Taper-lok fasteners

A series of groups of tests was examined, the results in each group (generally of ten specimens) being expressed as a fraction of the group mean. The results, in figure 112, clearly show the unusual distribution and the way in which the tail is reproduced by a double-family distribution with the second family subtracted from the first.

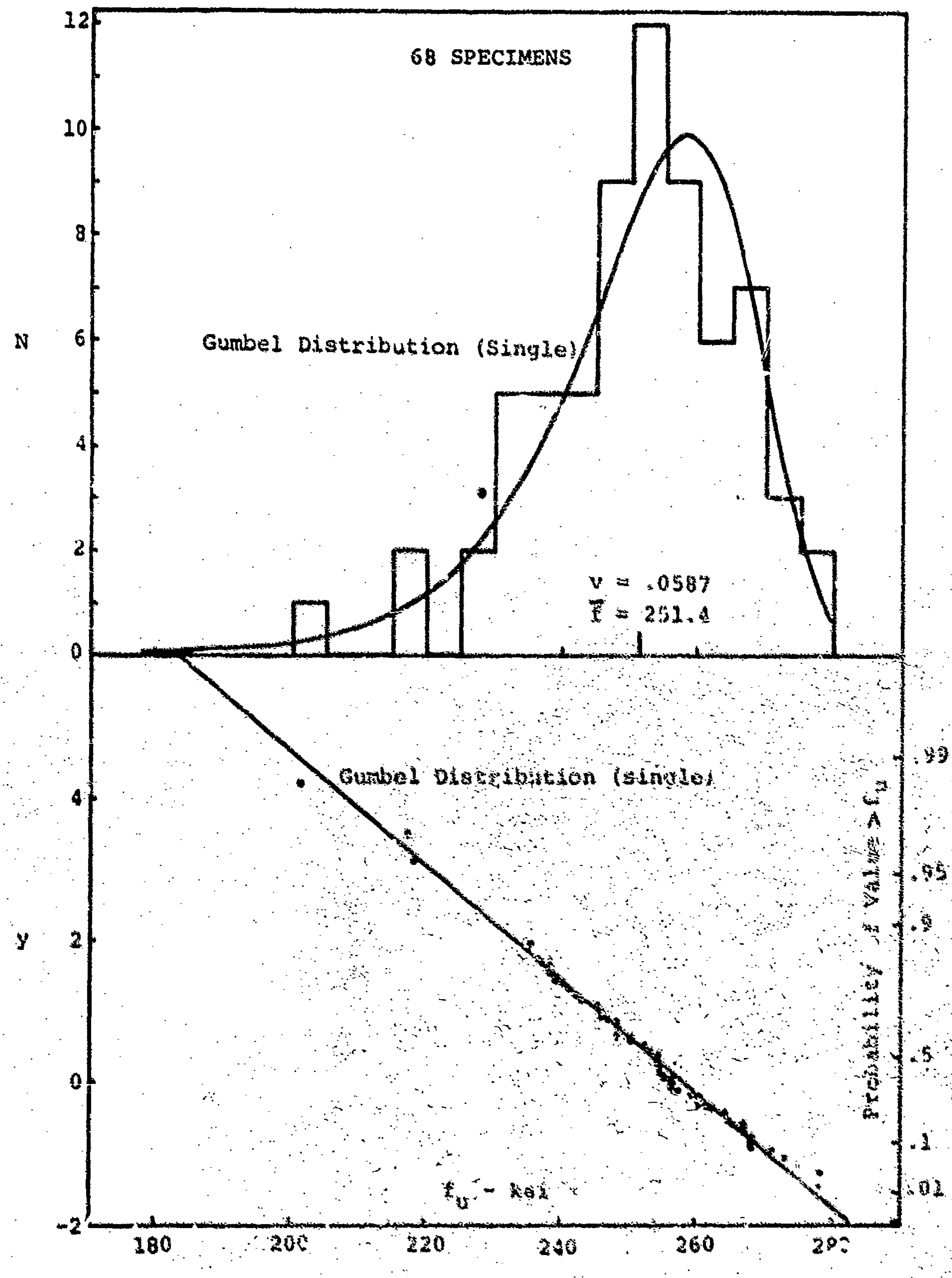
e. Lockbolts

Figures 113 and 114 give the results of analyses of two groups of Lock-bolt joint tests; each containing ten specimens only. While inconclusive as definitive values, the use of the two types of double-family distribution is demonstrated.



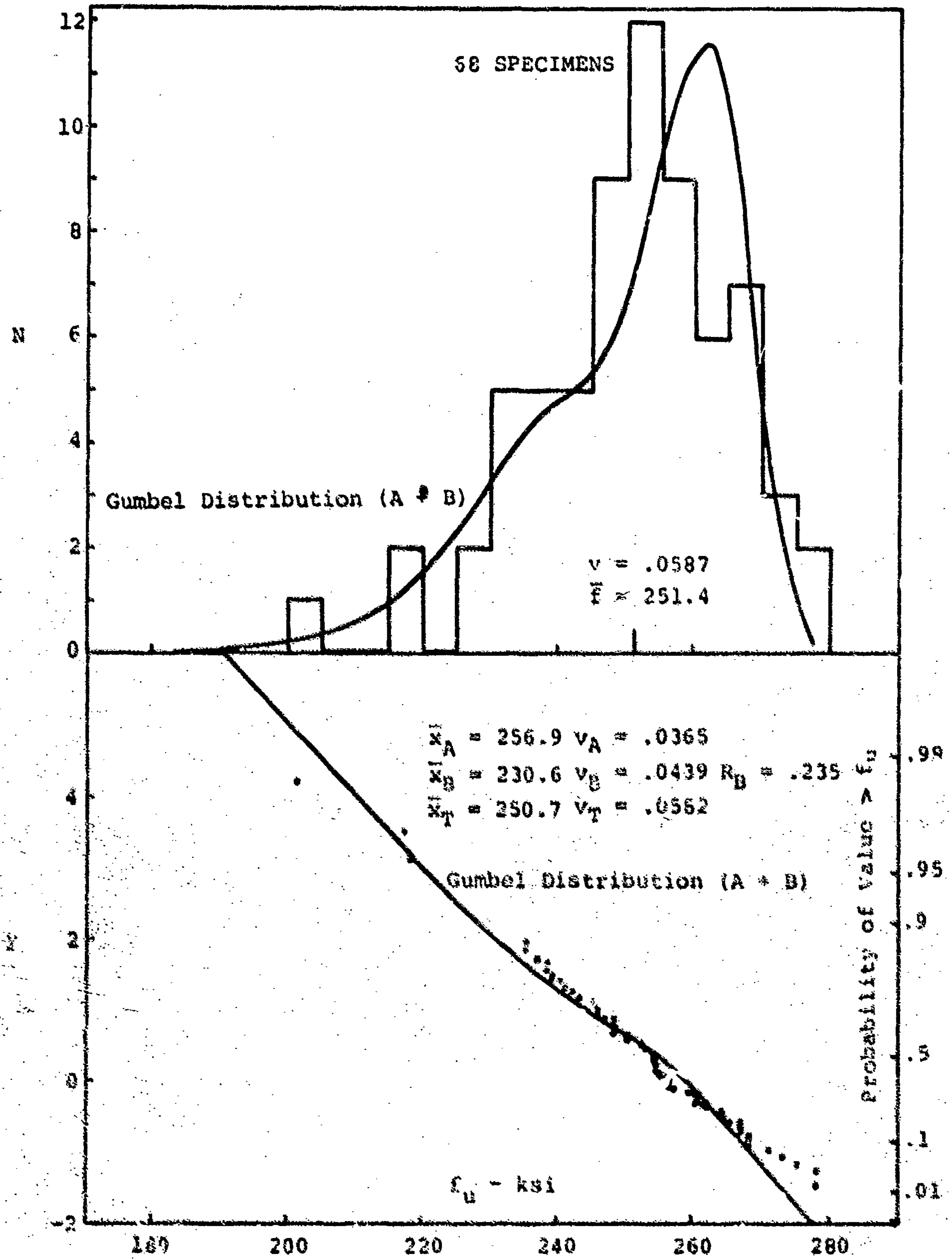
(a) Normal Distribution

FIGURE 109 BORON COMPOSITE STRENGTH



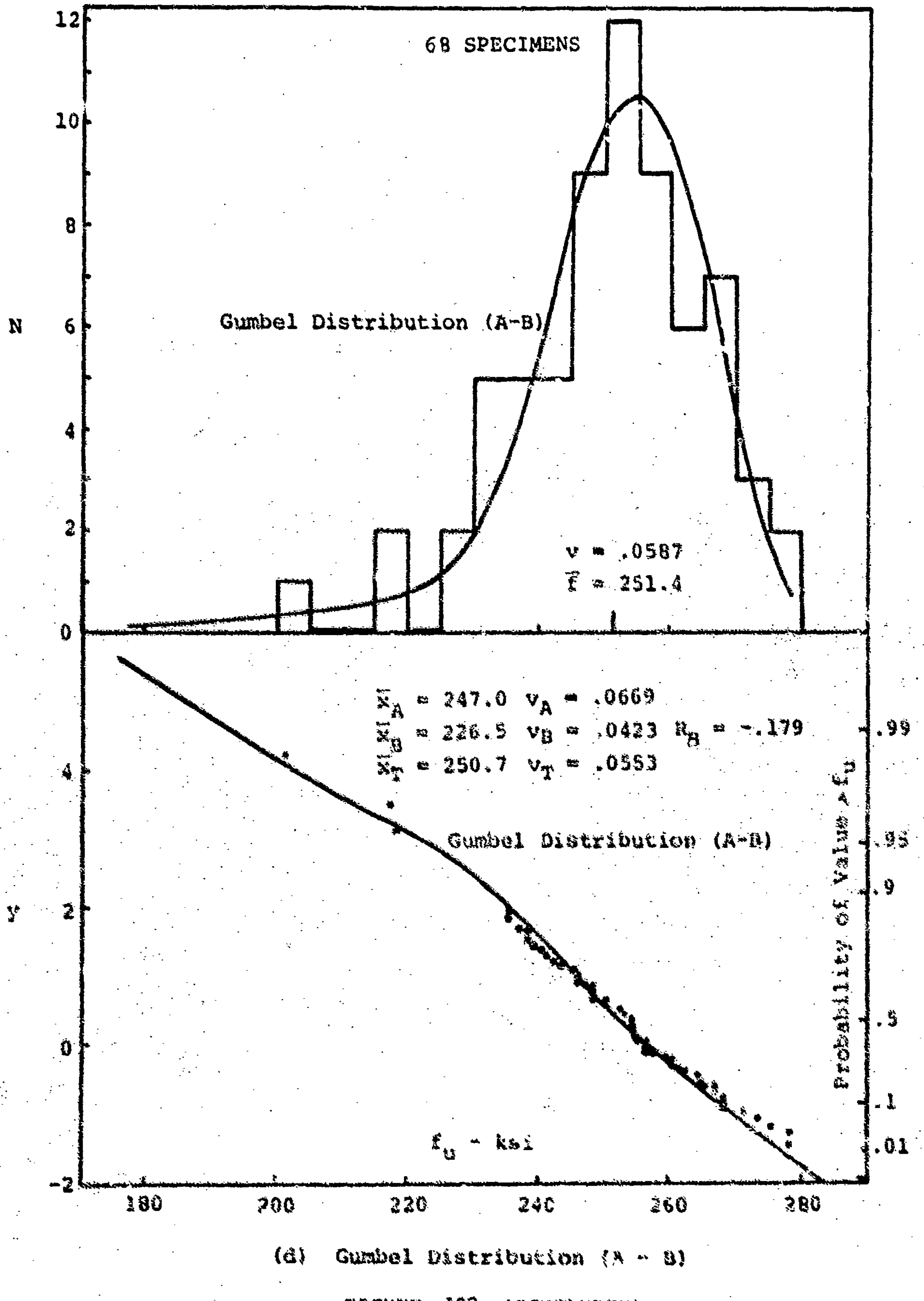
(b) Gumbel Distribution

FIGURE 109 (CONTINUED)



(c) Gumbel Distribution (A + B)

FIGURE 109 (CONTINUED)



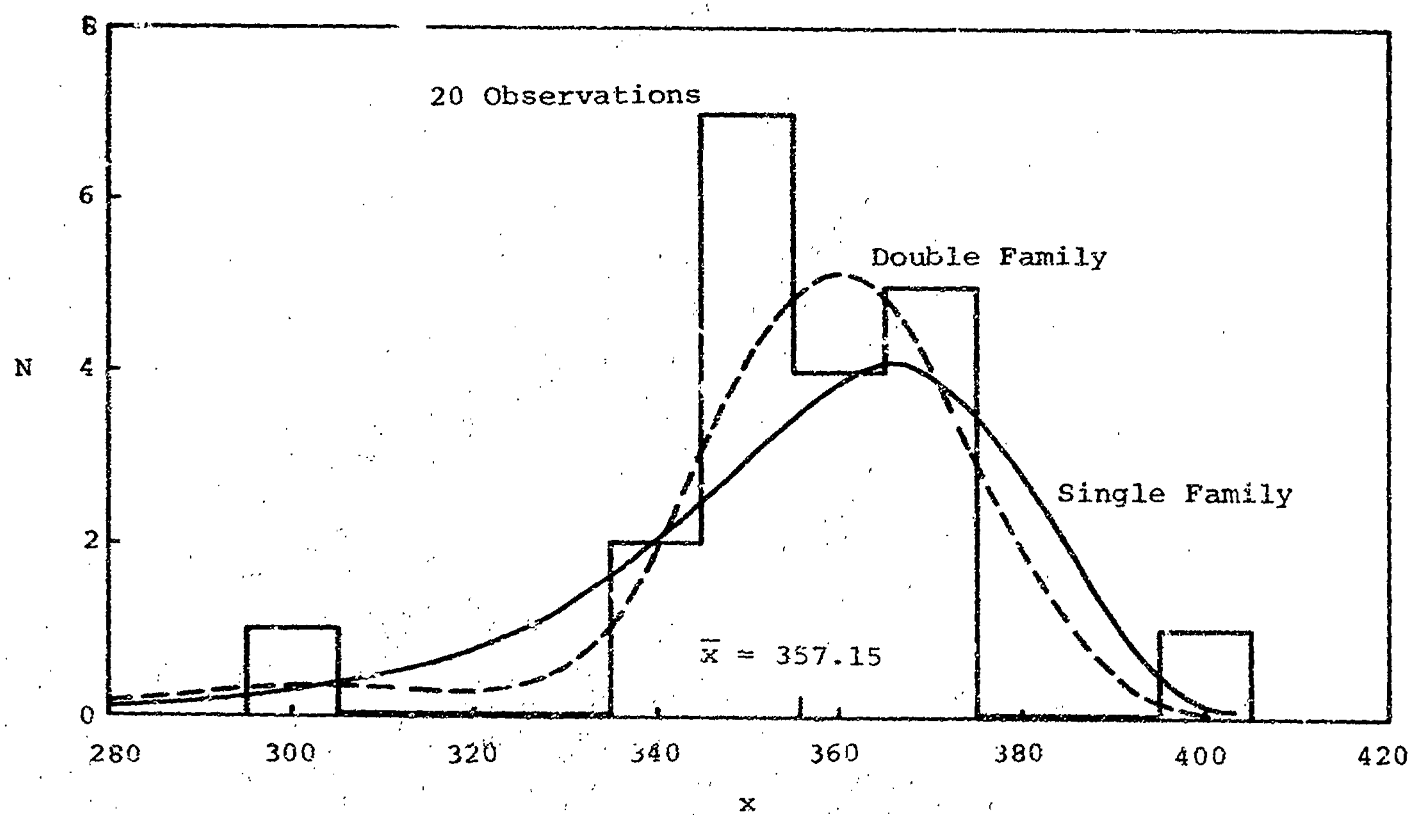
(d) Gumbel Distribution (A - B)

FIGURE 109 (CONCLUDED)

TABLE XLIV

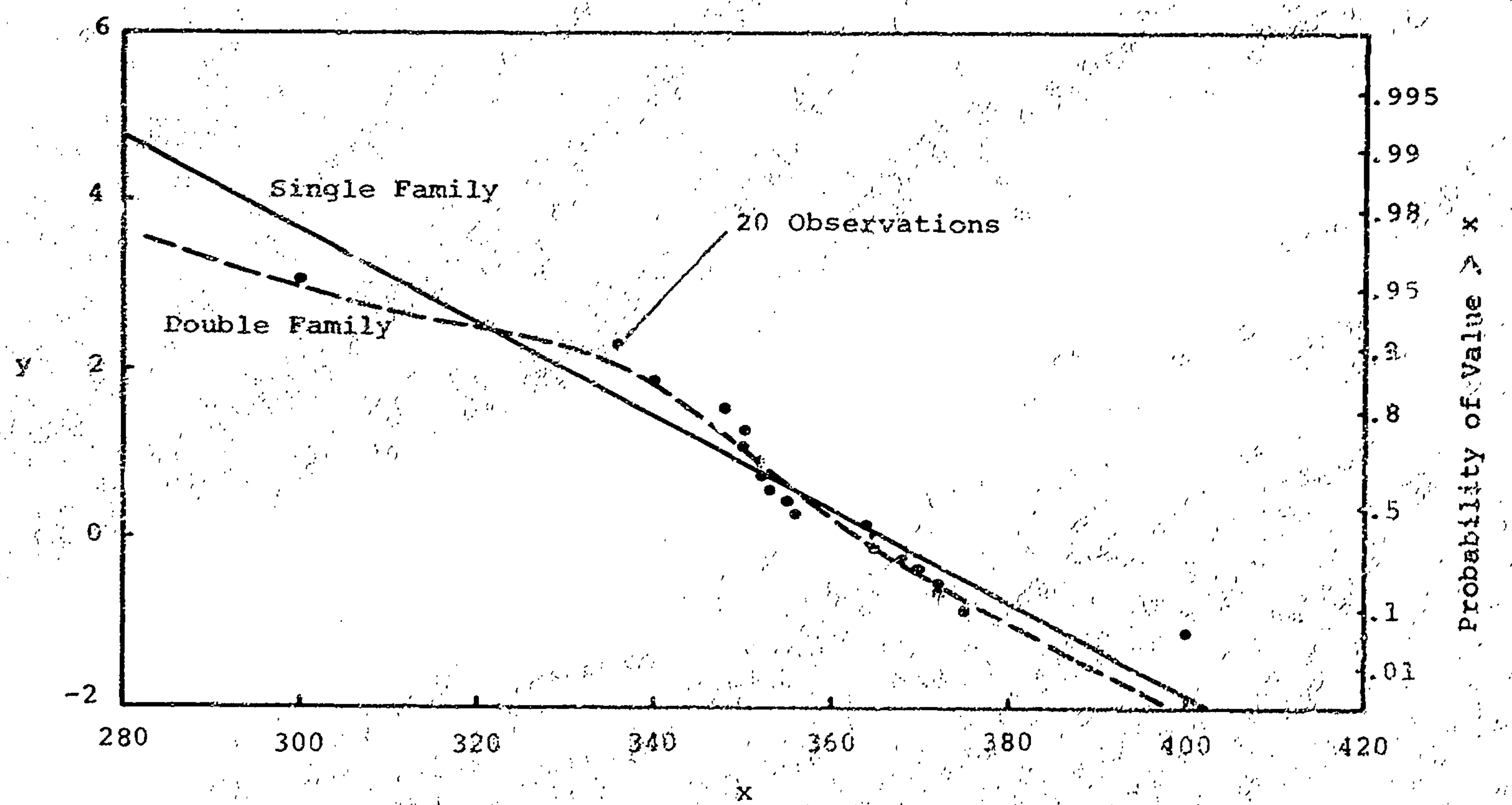
COMPARISON OF MATERIAL STRENGTH DATA

MATERIAL	DISTRIBUTION	STATISTICAL PARAMETERS					RESULTANT		
		x_A (ksi)	v_A (%)	p_B (%)	x_B (ksi)	v_B (%)	Mean (ksi)	v (%)	99% Value (ksi)
[illegible]	Normal	79.75	2.67	0	-	-	79.75	2.67	74.8
	Weibull, Single	79.75	2.67	0	-	-	79.75	2.67	72.7
	Weibull, Double	[illegible]	[illegible]	7.7	75.07	1.28	79.7[illegible]	2.66	73.[illegible]
[illegible] Steel	Normal	296.38	1.44	0	-	-	296.38	1.44	286.5
	Weibull, Single	[illegible]	1.44	0	-	-	296.38	1.44	282.[illegible]
	Weibull, Double	[illegible]	[illegible]	[illegible]	293.76	[illegible]	295.83	1.45	283.5
Ti	Normal	173.7	2.61	0	-	-	173.7	2.61	163.1
	Weibull, Single	173.7	2.61	0	-	-	173.7	2.61	155.7
	Weibull, Double	[illegible]	1.54	[illegible]	[illegible]	[illegible]	173.2	2.64	159.7
[illegible] Composite	Normal	251.4	5.87	0	-	-	251.4	5.87	217.0
	Weibull, Single	251.4	[illegible]	0	-	-	251.4	5.87	201.5
	Weibull, [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.39	250.7	5.82	205.0
	Weibull, [illegible]	[illegible]	[illegible]	[illegible]	226.45	4.23	250.7	5.53	193.0



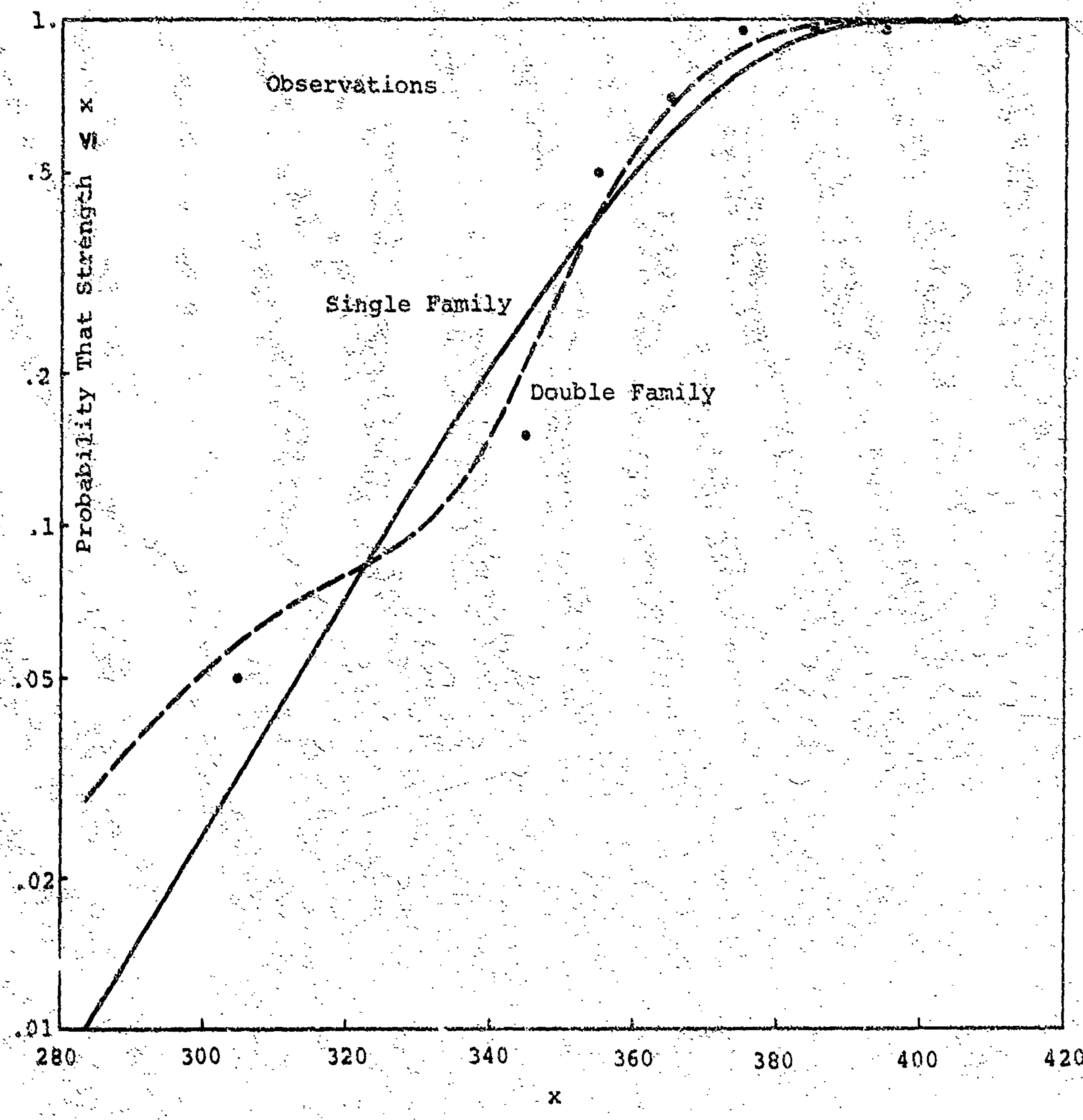
(a) FREQUENCY DISTRIBUTION

FIGURE 110 AD5 RIVET (T= .05) STRENGTH



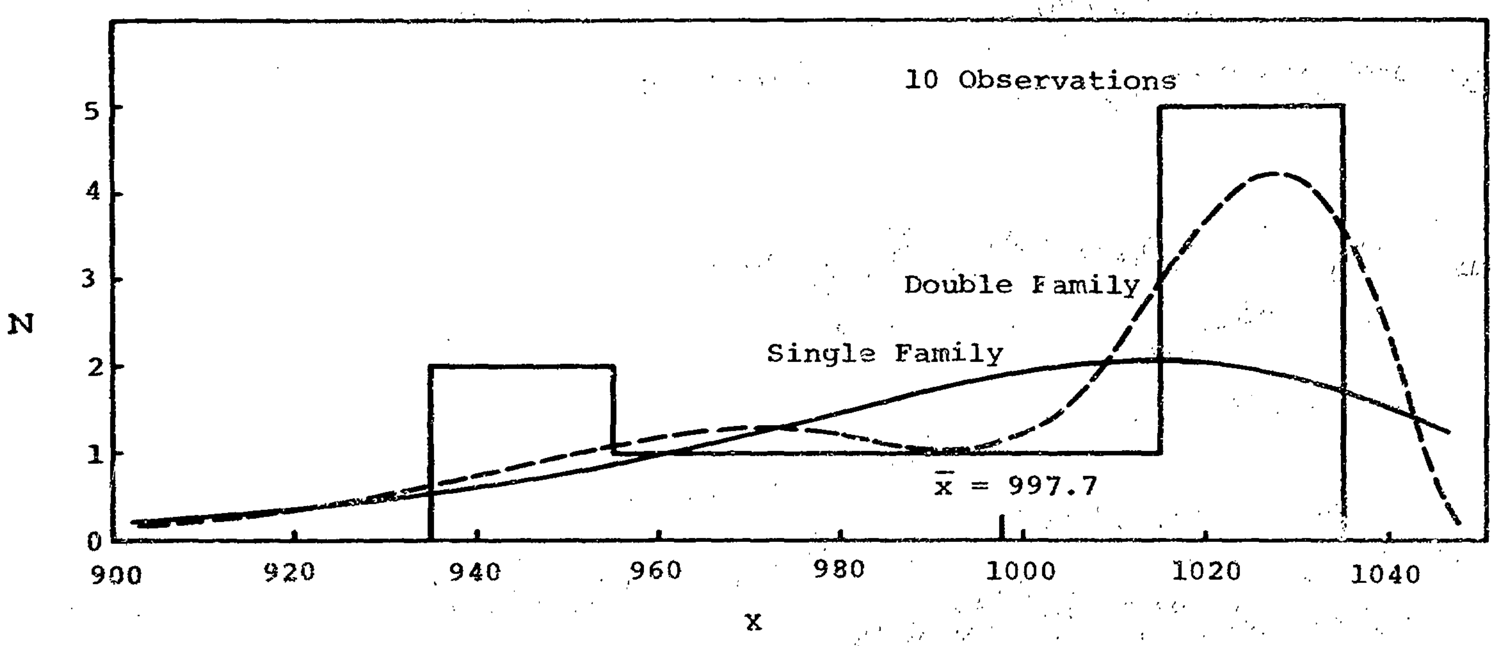
(b) CUMULATIVE DISTRIBUTION

FIGURE 110 (CONTINUED)



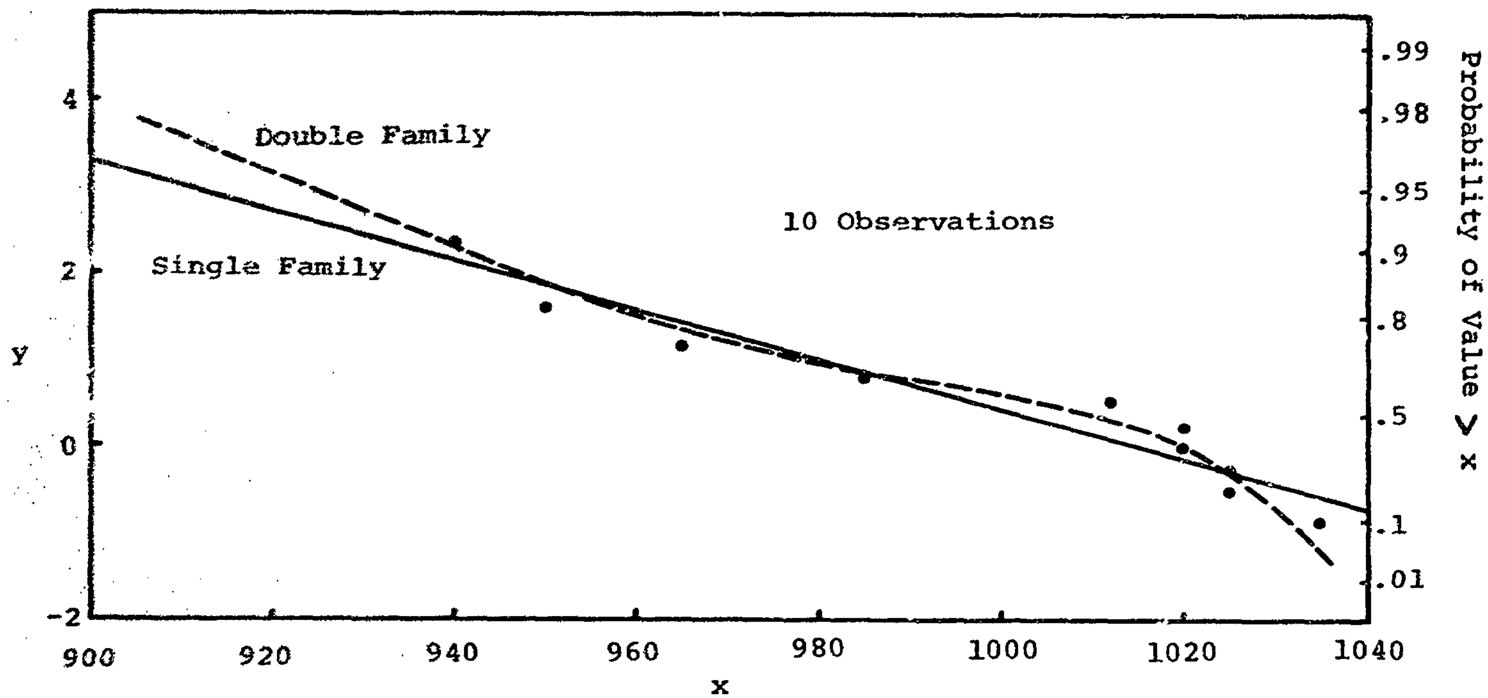
(c) CUMULATIVE PROBABILITY

FIGURE 110 (CONCLUDED)



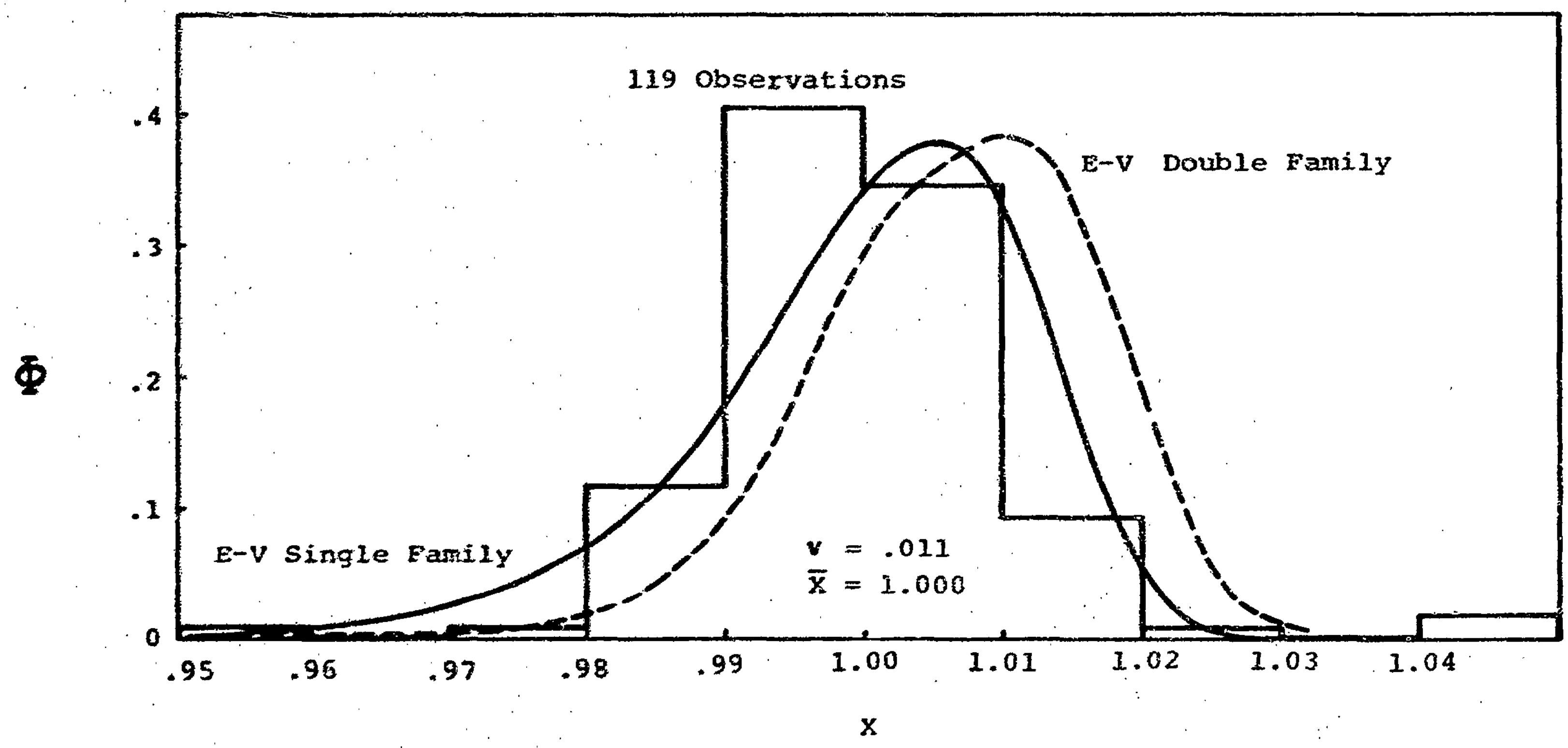
(a) FREQUENCY DISTRIBUTION

FIGURE 111 D6 RIVET (T = .09) STRENGTH



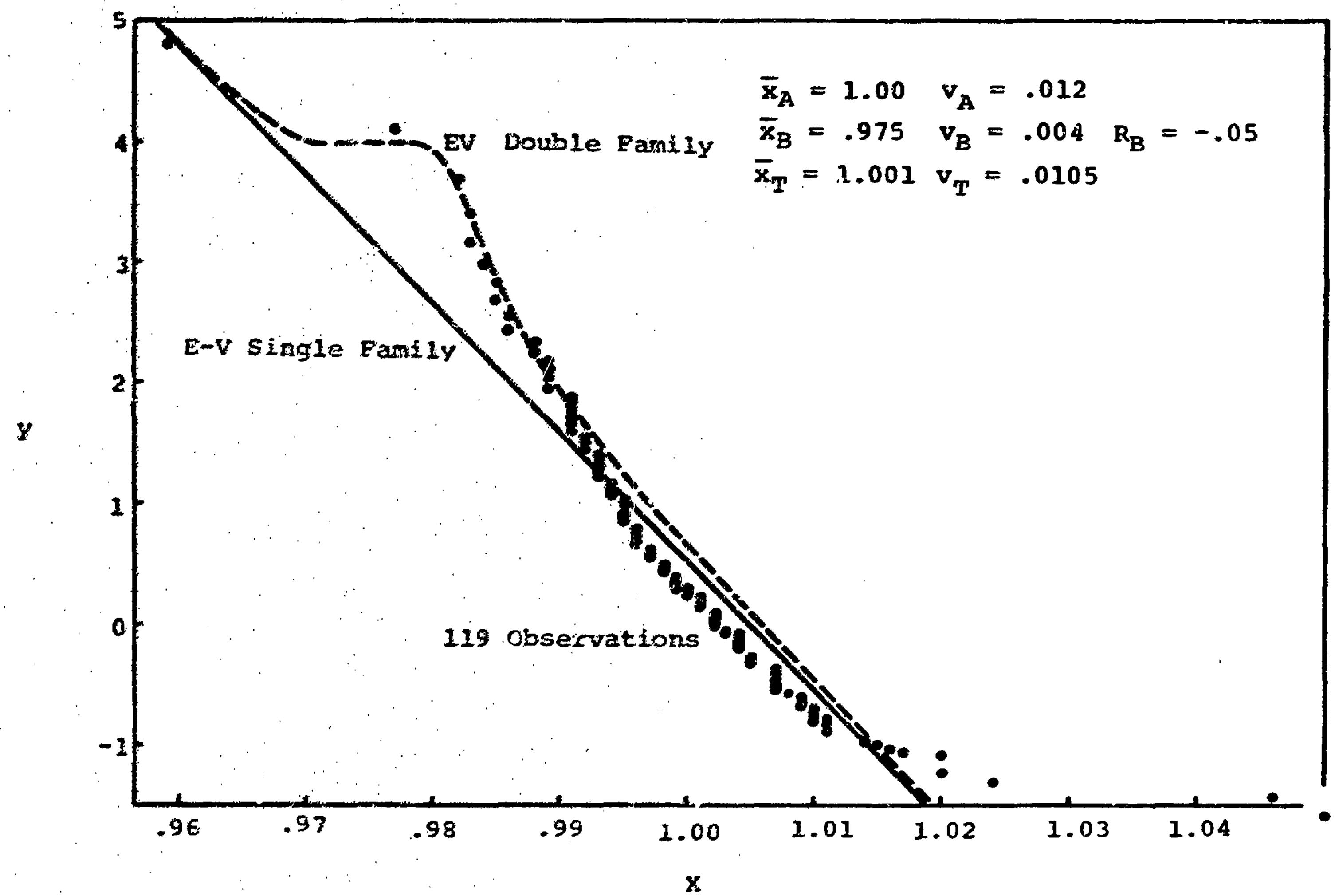
(b) CUMULATIVE DISTRIBUTION

FIGURE 111 (CONCLUDED)



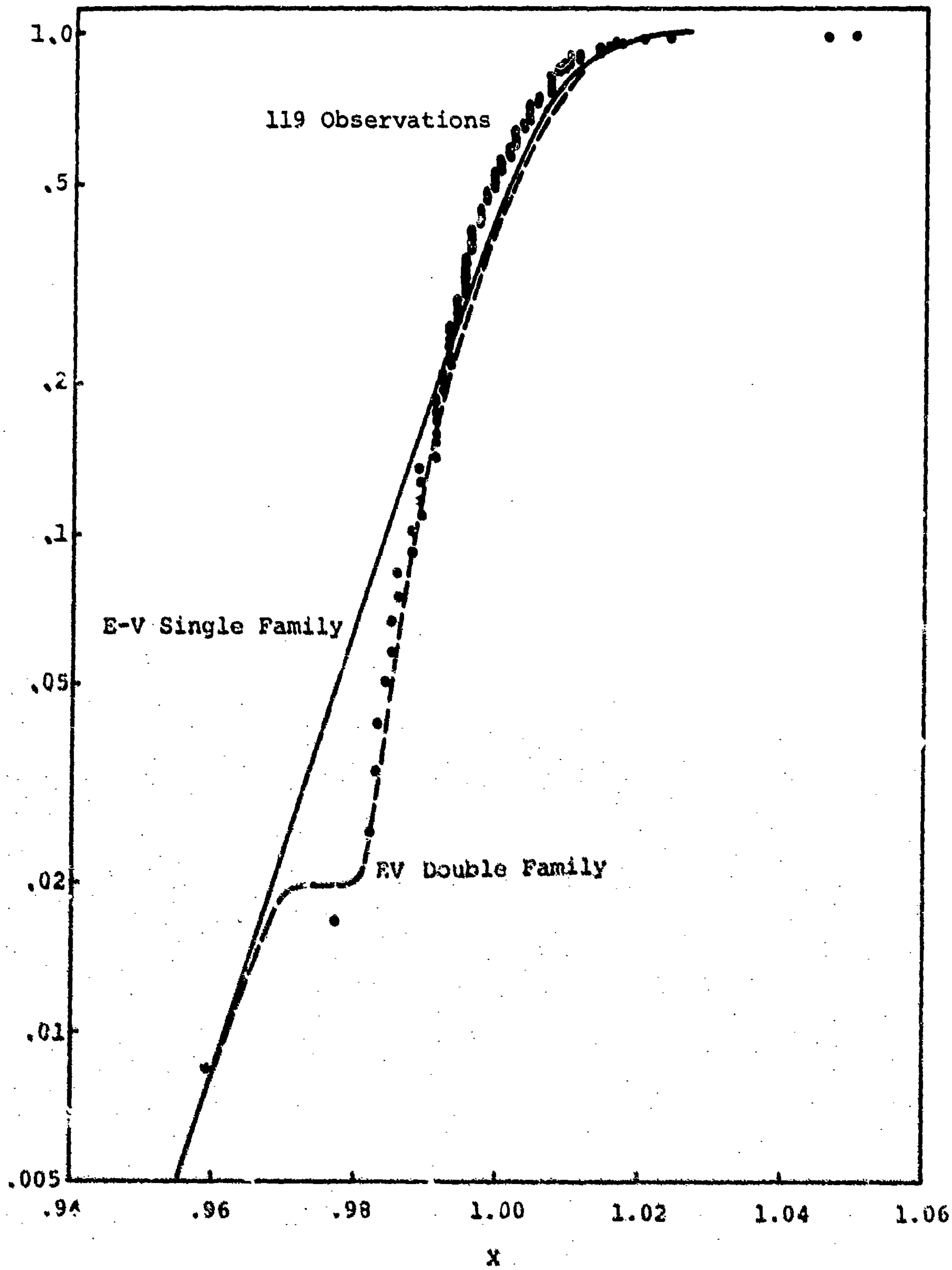
(a) FREQUENCY DISTRIBUTION

FIGURE 112 TAPERLOK (3/16 & 1/4) STRENGTH



(b) CUMULATIVE DISTRIBUTION

FIGURE 112 (CONTINUED)



(c) CUMULATIVE PROBABILITY

FIGURE 112 (CONCLUDED)

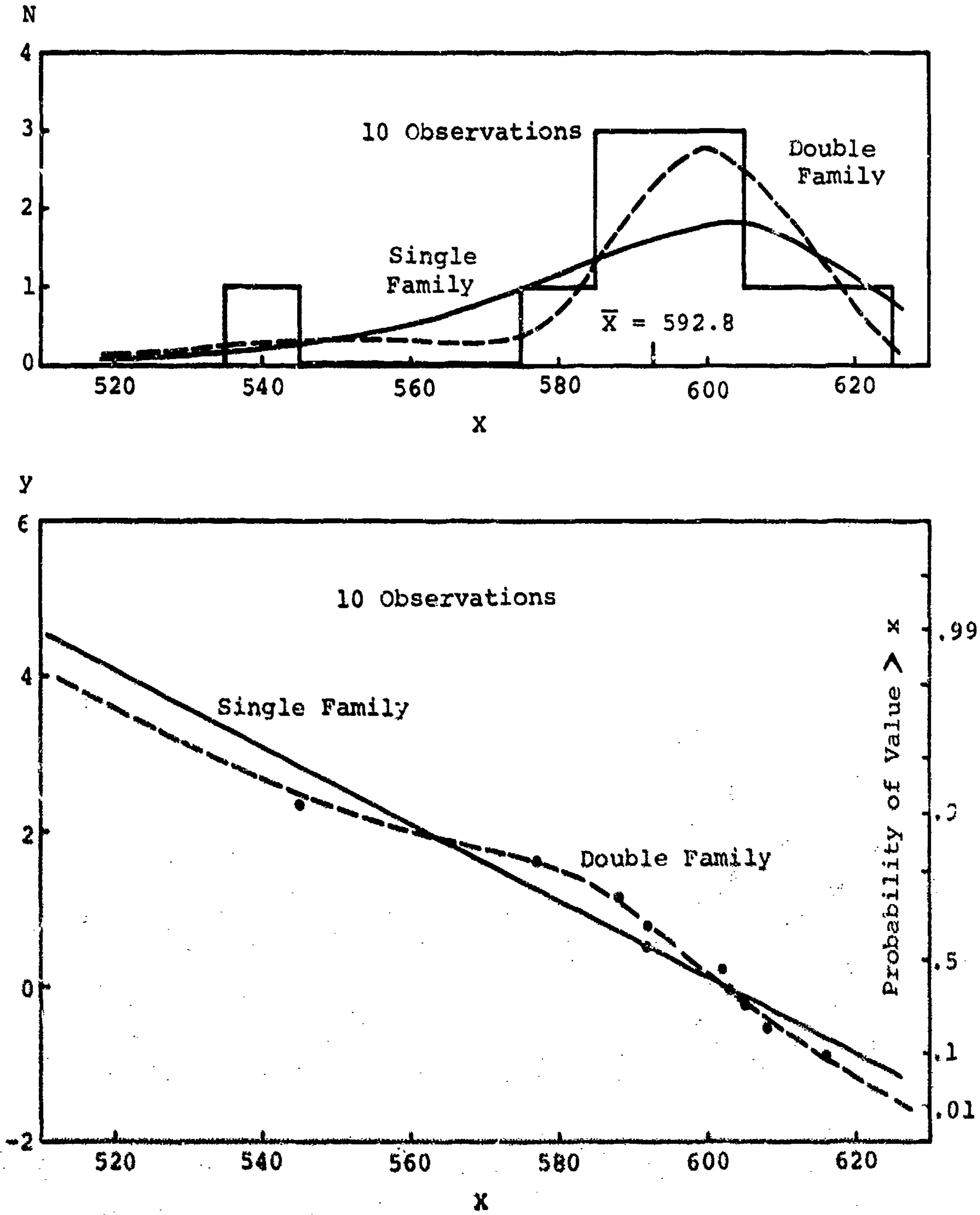
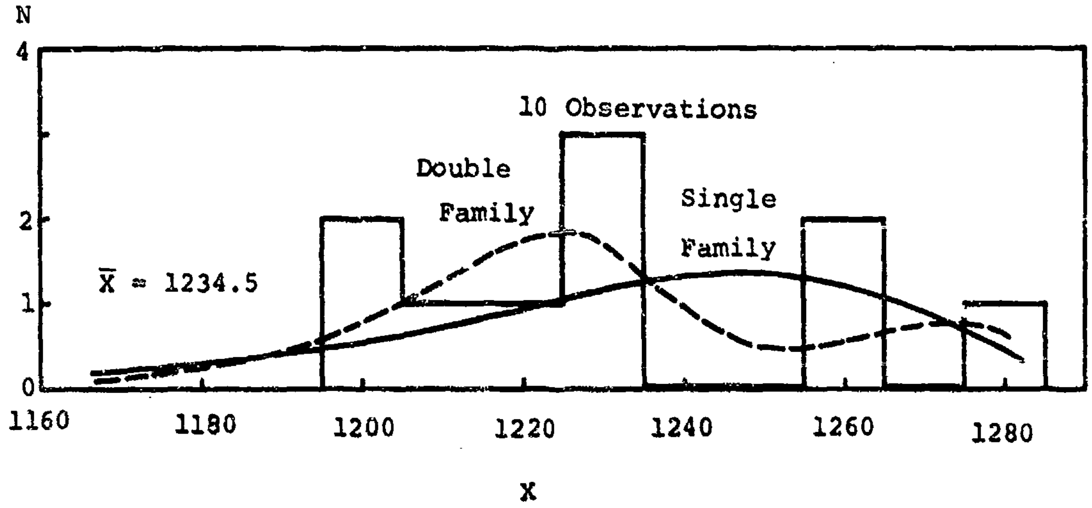


FIGURE 113 T6 LOCKBOLT (T = .05) STRENGTH



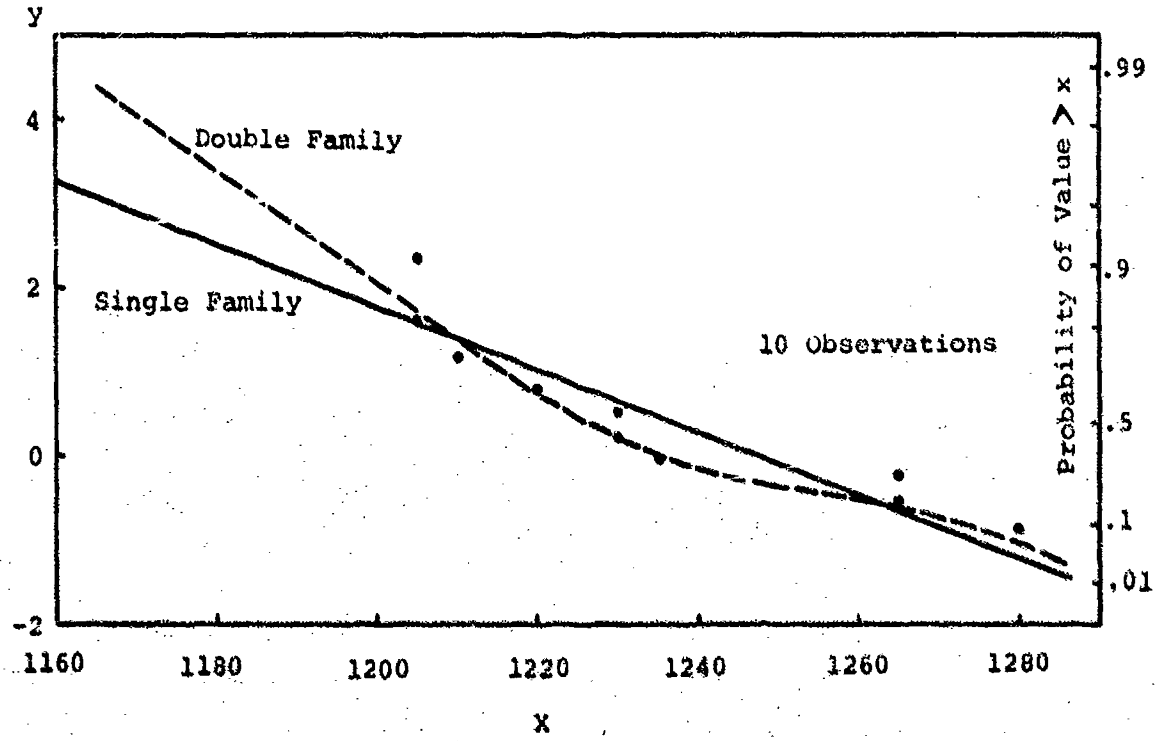


FIGURE 114 T6 LOCKBOLT (T = .09) STRENGTH

A5.5 Conclusions

a. The inaccuracies which can result from the assumption that a data sample has any particular distribution shape must be emphasized; selection of a distribution must be based on examination of the data to be represented.

The importance of representing the tails of the distributions (upper end for loads, lower end for strength) needs special care in the prediction of failure risks, since it is these tails which are most important.

b. The realization that the equations are simply a means of expressing the characteristics of the important parts of observed distributions in a convenient algebraic fashion (whether the equations are normal, log-normal, Weibull, Gumbel, Pearson, etc. is of no consequence) will avoid the charge made by Andrew Lang on the man who "uses statistics as a drunken man uses lamp-posts: for support, not for illumination."

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